Jet Modification as a function of energy lost and jet mass depletion

Abhijit Majumder
Wayne State University

Riken BNL High pT workshop April 2016

Outline

1) MC generation and base mode

2) Review of MATTER and role of virtuality

3) Mass, virtuality scale

4) virtuality vs. distance

5) From virtuality to reconstructed mass

6) Sensitivity to R

7) Mass as a window to strong and weak coupling

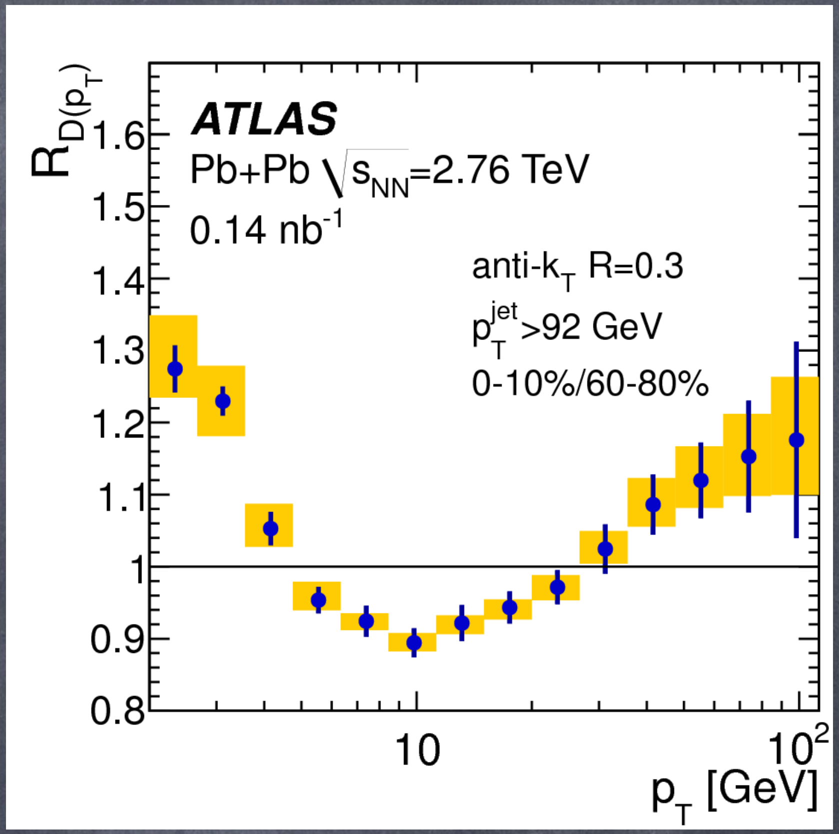
other messages in this talk!

- Realism!
  Calculations on a hydro
- Event generators
  the method of the future
- Mixture of strong and weak coupling
  a requirement of all calculations.

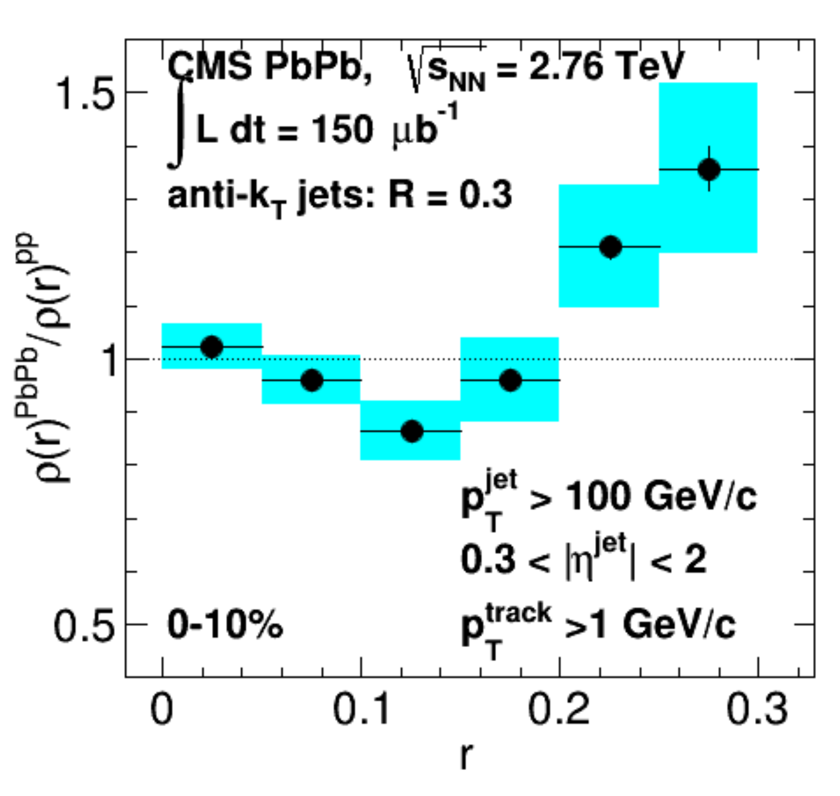
Motivation

We now have intra-jet data

obtained by comparing medium modified and vacuum jets
at the same energy



But is Energy the only way to classify a jet?

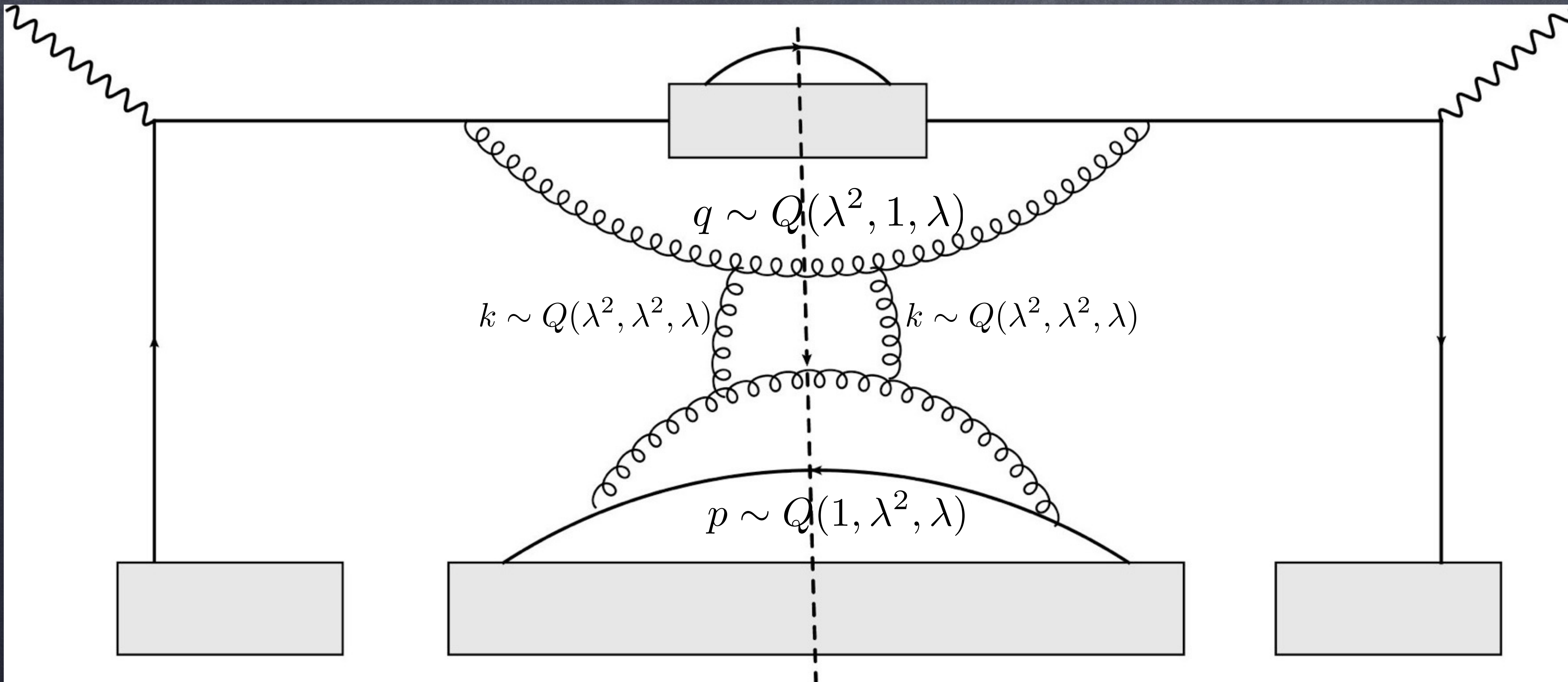


Jet Mass: a boost invariant property of a jet.

To study this, need a MC generator

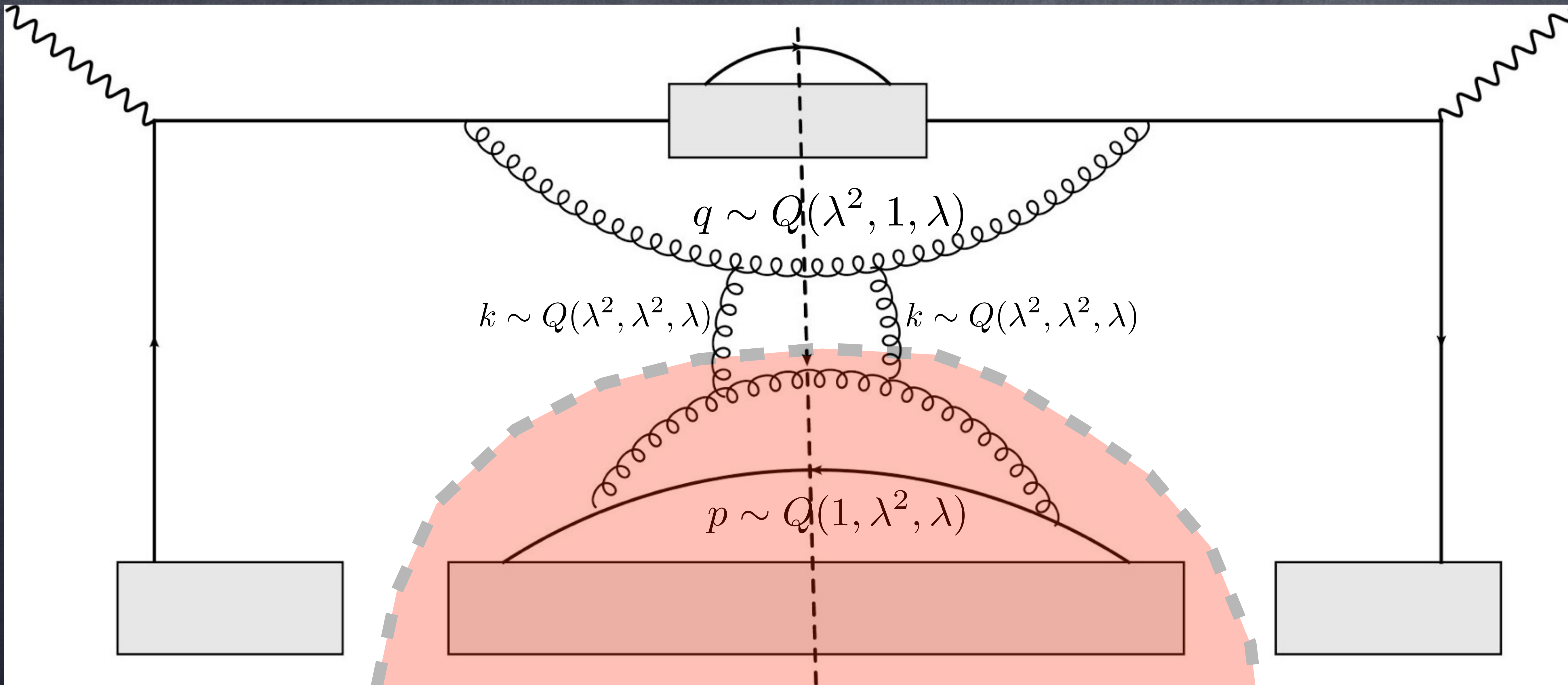
Details of HT-MC code MATTER

Modular All Twist Transverse Elastic scattering and Radiation



Details of HT-MC code MATTER

Modular All Twist Transverse Elastic scattering and Radiation



All of this evolution is hiding within $\hat{q}$

Light quark modification is sensitive to the high Q^2, low-x part of the in-medium gluon distribution.

Varieties of MC generators

Bottom-up MC generators:

JEWEL, YaJEM

Top-Down generators:

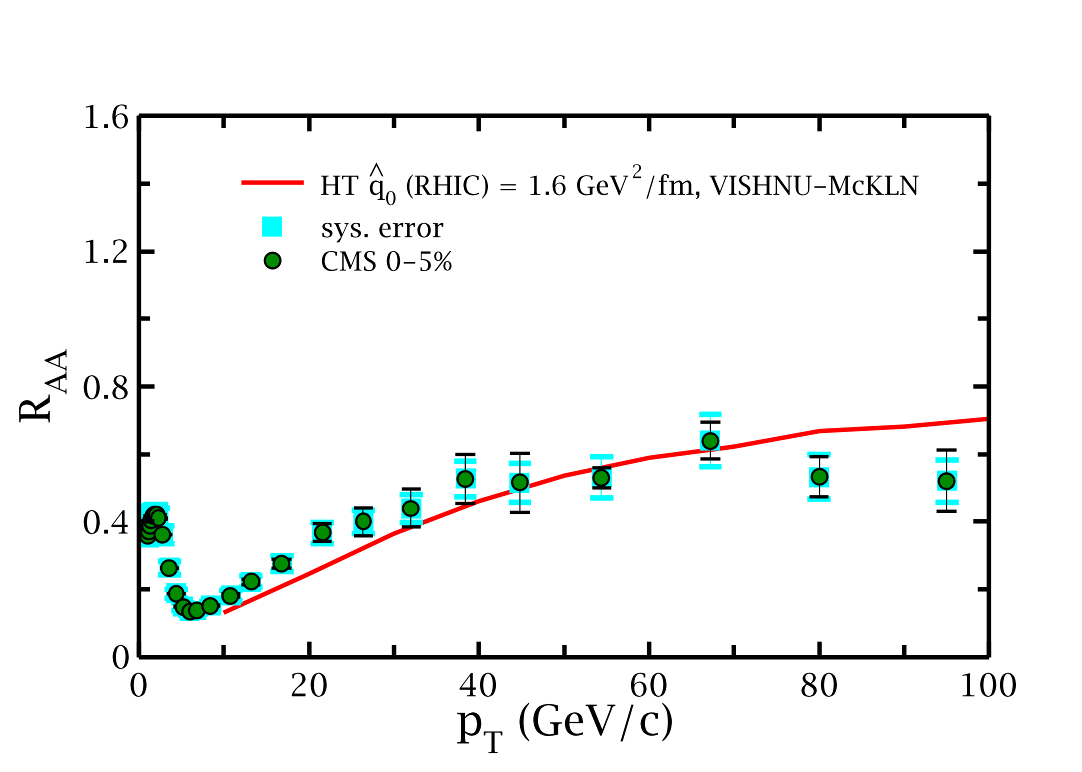
MARTINI, MATTER, Q-PYTHIA

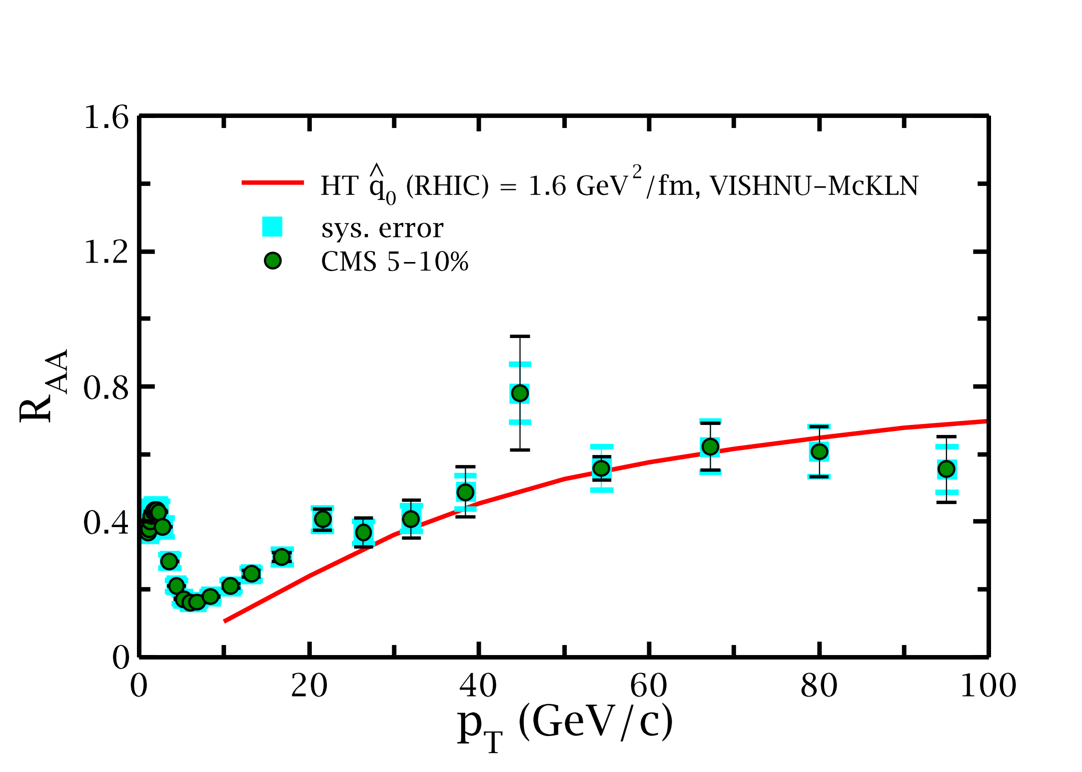
Hybrid generators,

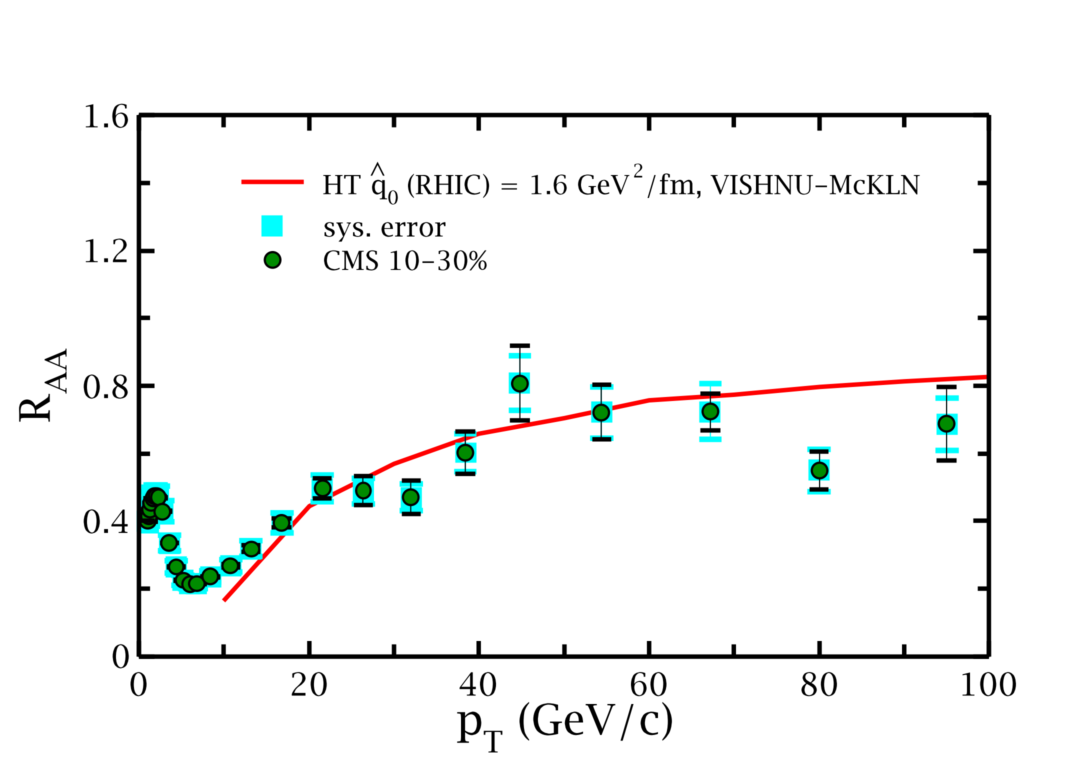
PYQUEN

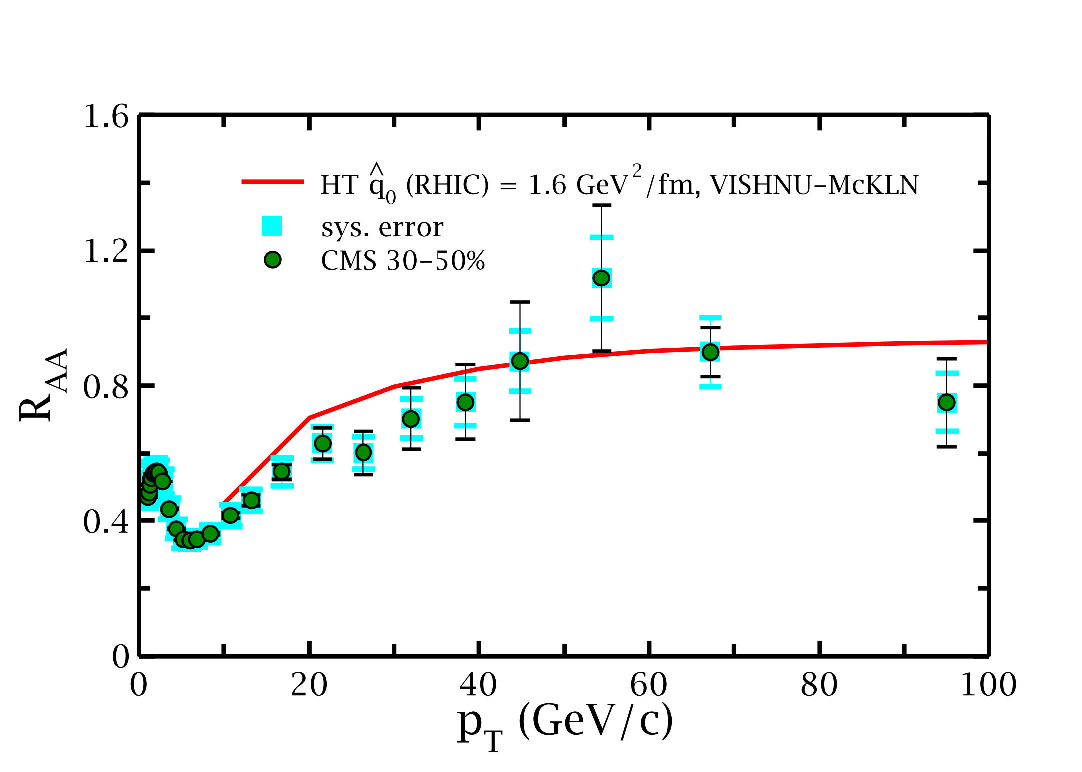
How good is your base formalism?

Tested in a 2+1D viscous hydro simulation

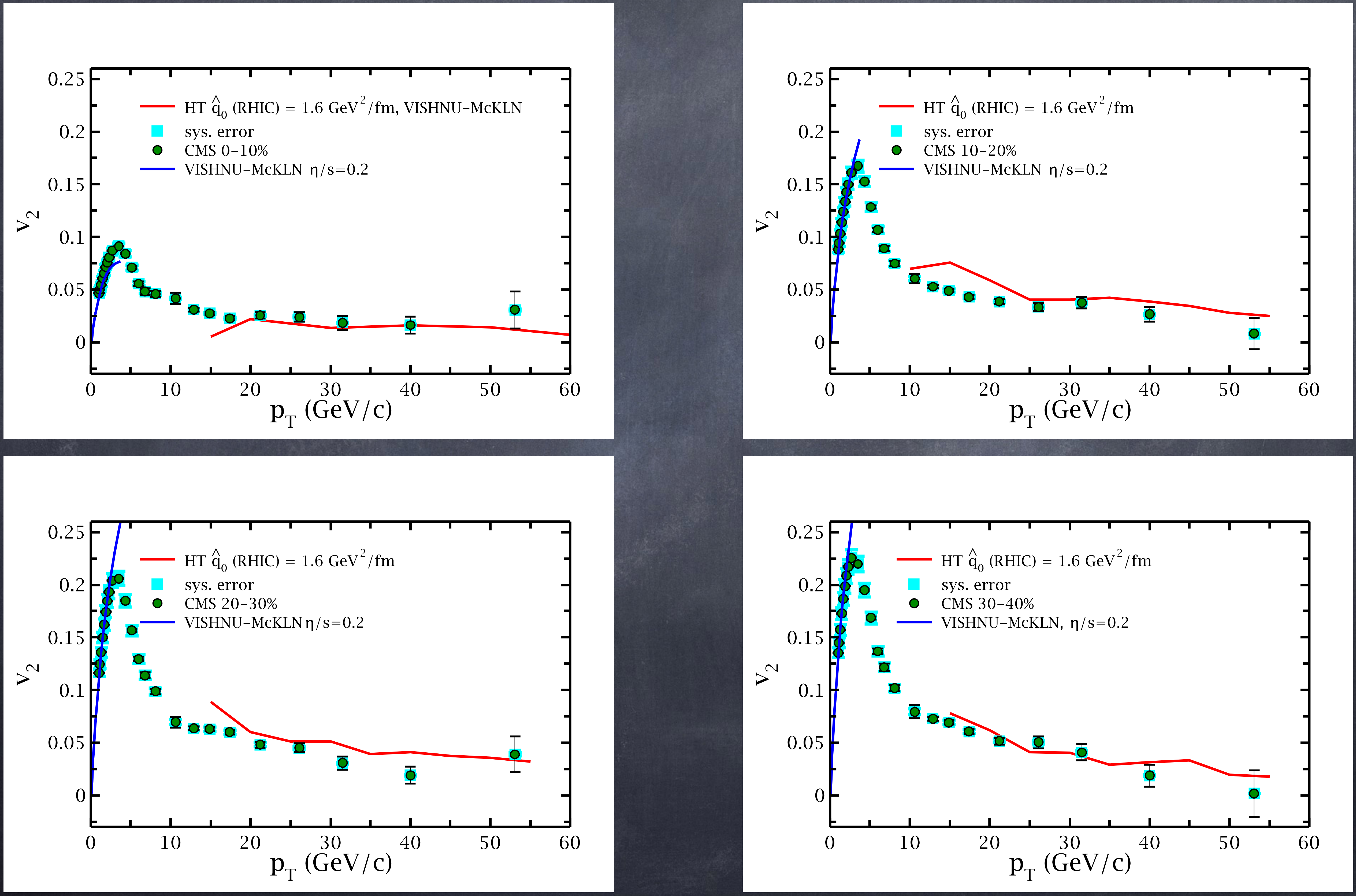




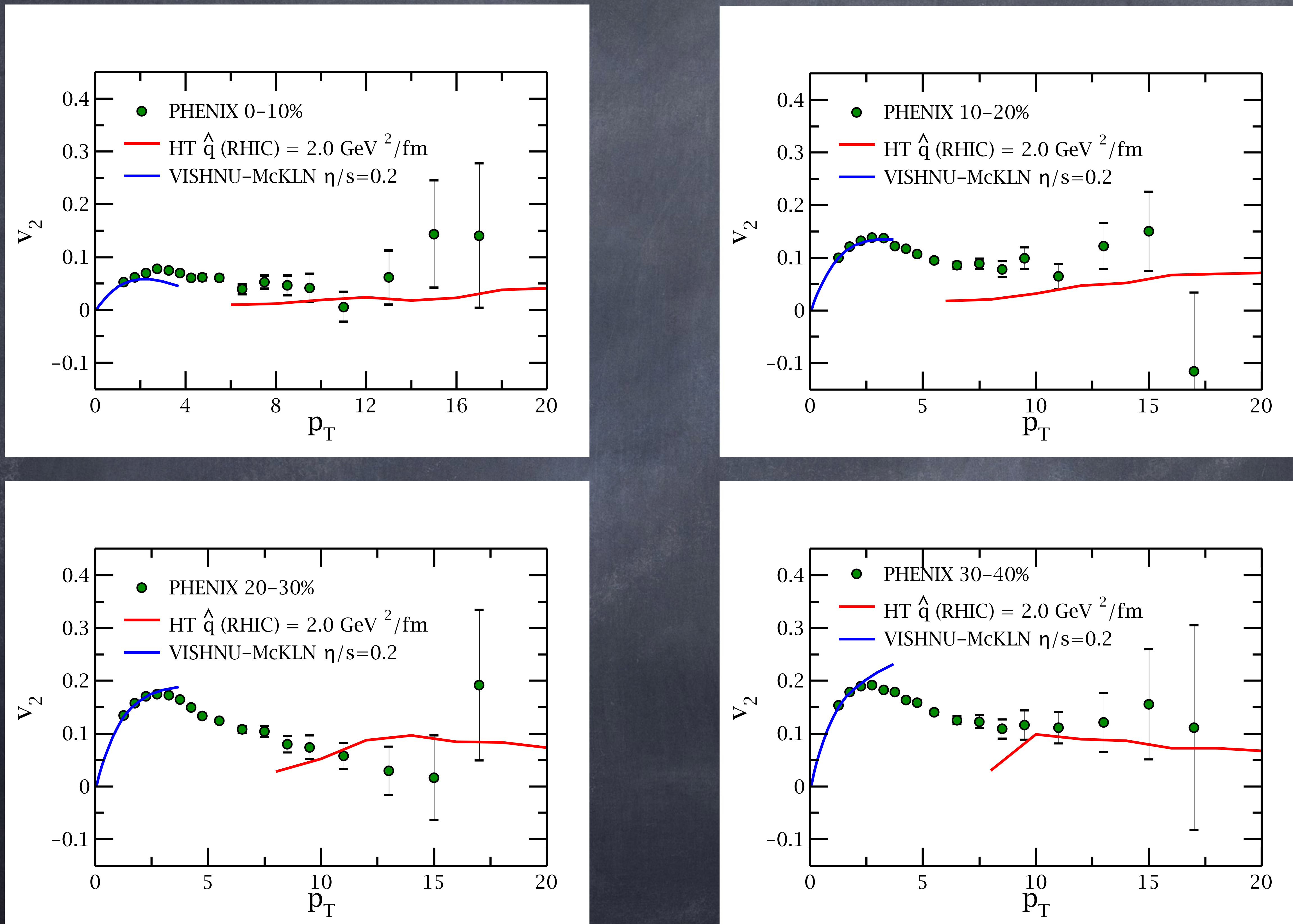




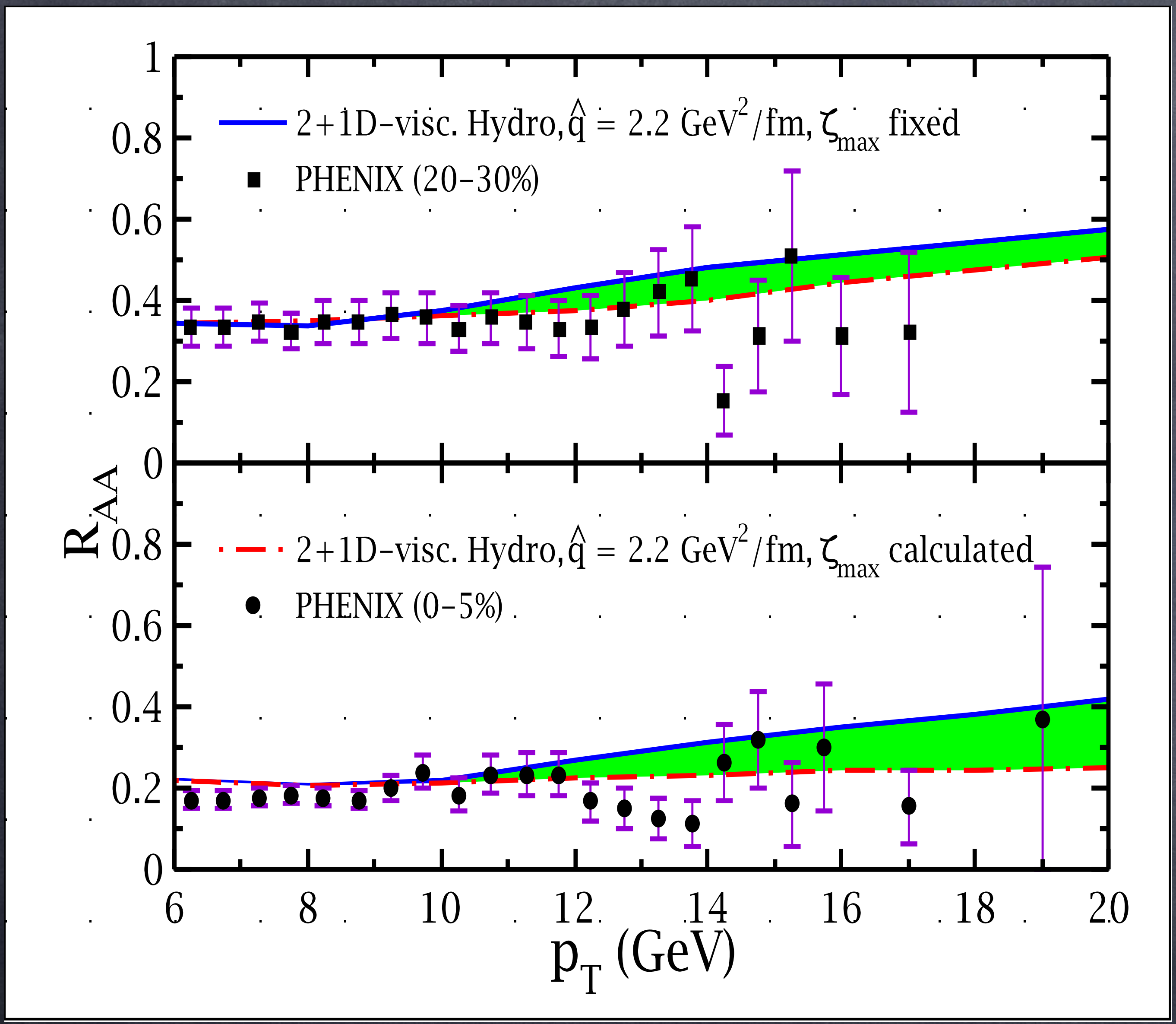
v_2 at LHC without a bump in $\hat{q}/T^3$

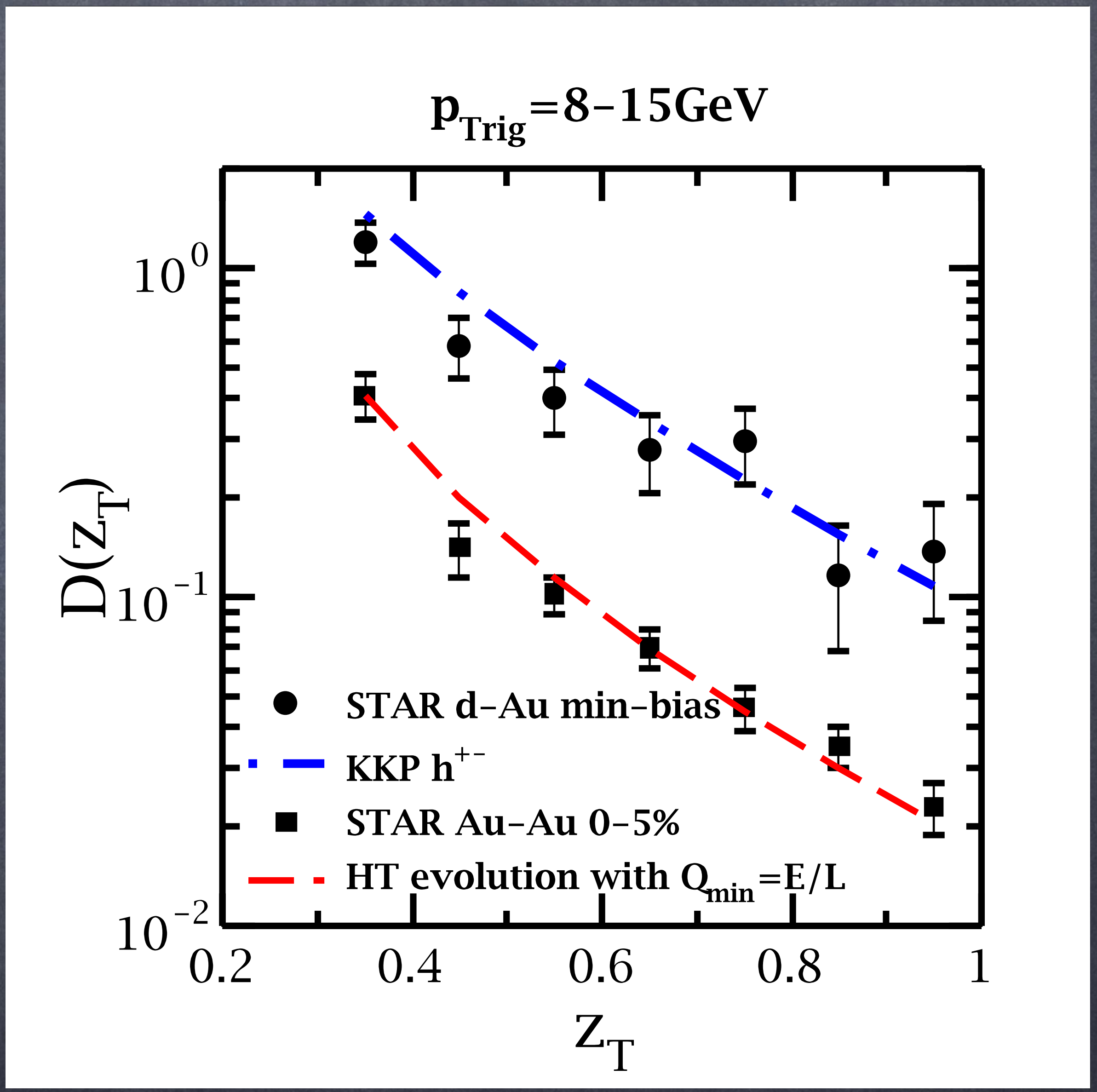


v_2 at RHIC without a bump in $\hat{q}/T^3$



Tested in parameter free extensions to away side





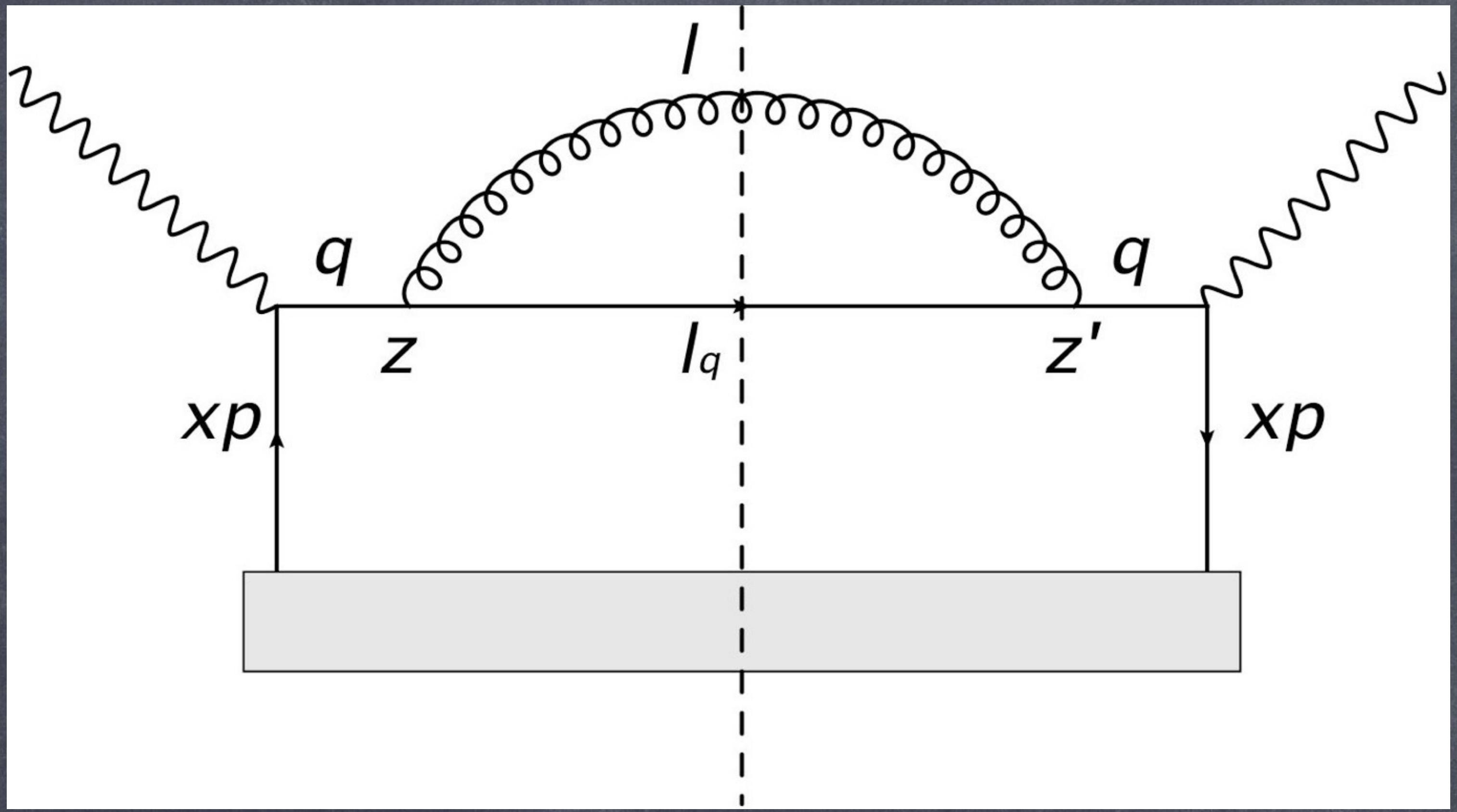
And extrapolated to LHC energies!

MATTER review

Main problem: Introducing distance into a DGLAP shower

No space-time in the usual Monte-Carlo showers

$$\bar{z} = \frac{z + z'}{2}$$



$$\delta z = z - z'$$

what is the role of z and z' ?

$$\int_0^\infty d^4\bar{z} \exp\left[i(\delta q)\bar{z}\right] \qquad \int d^4\delta z \exp\left[i\delta z(l + l_q - q)\right]$$

δq is the uncertainty in q,

How much uncertainty can there be ?

To be sensible: $\delta q \ll q$

we assume a Gaussian distribution around q^+

And try different functional forms of the width

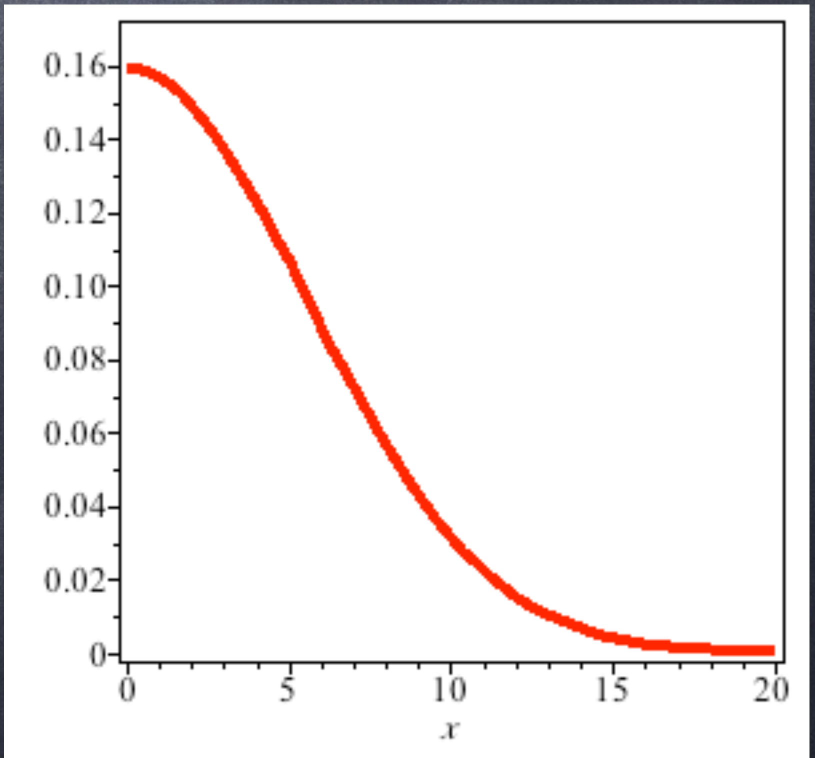
We set the form by insisting $\langle\tau\rangle = 2q^-/(Q^2)$

to obtain the z^- distribution only need to assume a δq^+ distribution

$$\rho(\delta q^+) = \frac{e^{-\frac{(\delta q^+)^2}{2[2(q^+)^2/\pi]}}}{\sqrt{2\pi[2(q^+)^2/\pi]}}$$

A normalized Gaussian with a variance $2q^+/\pi$

FT gives the following distribution in distance



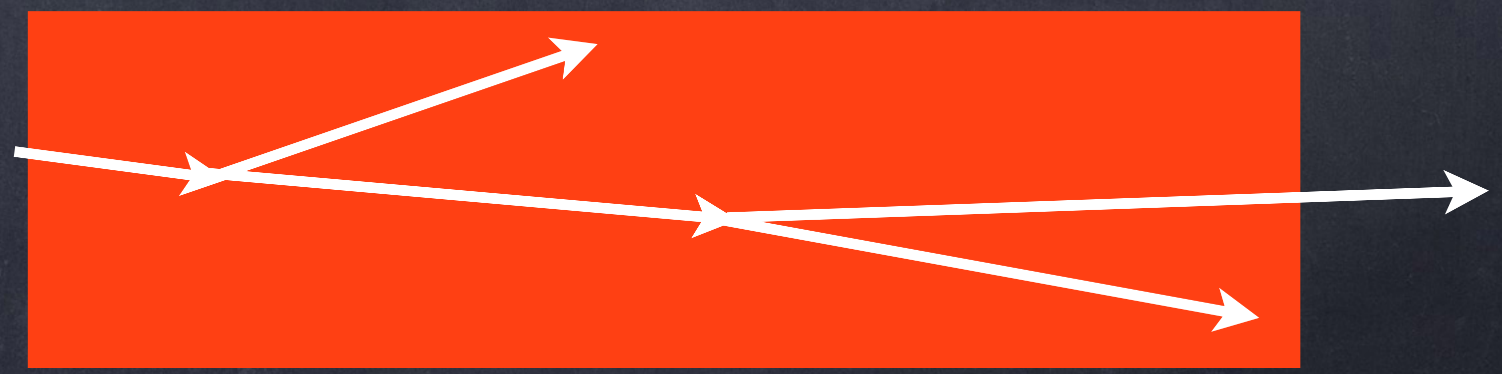
Constructing the Sudakov form factor

$$S_{\zeta_i^-}(Q_0^2, Q^2) = \exp\left[- \int_{2Q_0^2}^{Q^2} \frac{d\mu^2}{\mu^2} \frac{\alpha_S(\mu^2)}{2\pi} \right.$$

$$\left. \times \int_{Q_0/Q}^{1-Q_0/Q} dy P_{qg}(y) \left\{ 1 + \int_{\zeta_i^-}^{\zeta_i^- + \tau^-} d\zeta K_{p^-,\mu^2}(y,\zeta) \right\} \right]$$

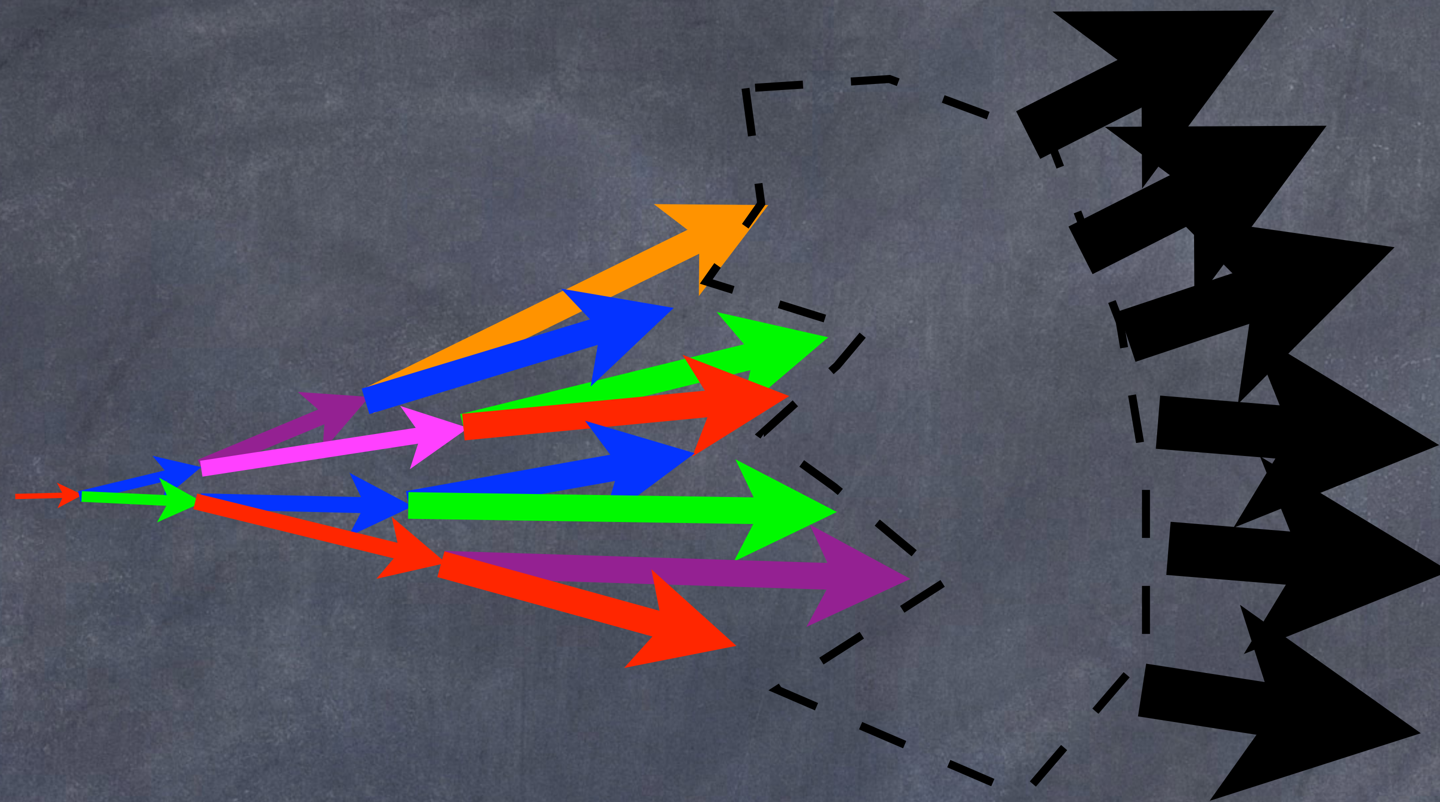
$$K_{p^-,\mu^2}(y,\zeta) = \frac{2\hat{q}}{\mu^2}\left[2 - 2\cos\left\{ \frac{\mu^2(\zeta - \zeta_i)}{2p^- y(1-y)} \right\} \right]$$

Valid as long as, $\dfrac{\hat{q}\tau}{\mu^2} \lesssim 1$



Mass, Virtuality and Scale

$$\int_{Q_0^2}^{Q^2} d\mu^2$$



Q^2 is the scale,

μ is the mass of jet = virtuality of first parton

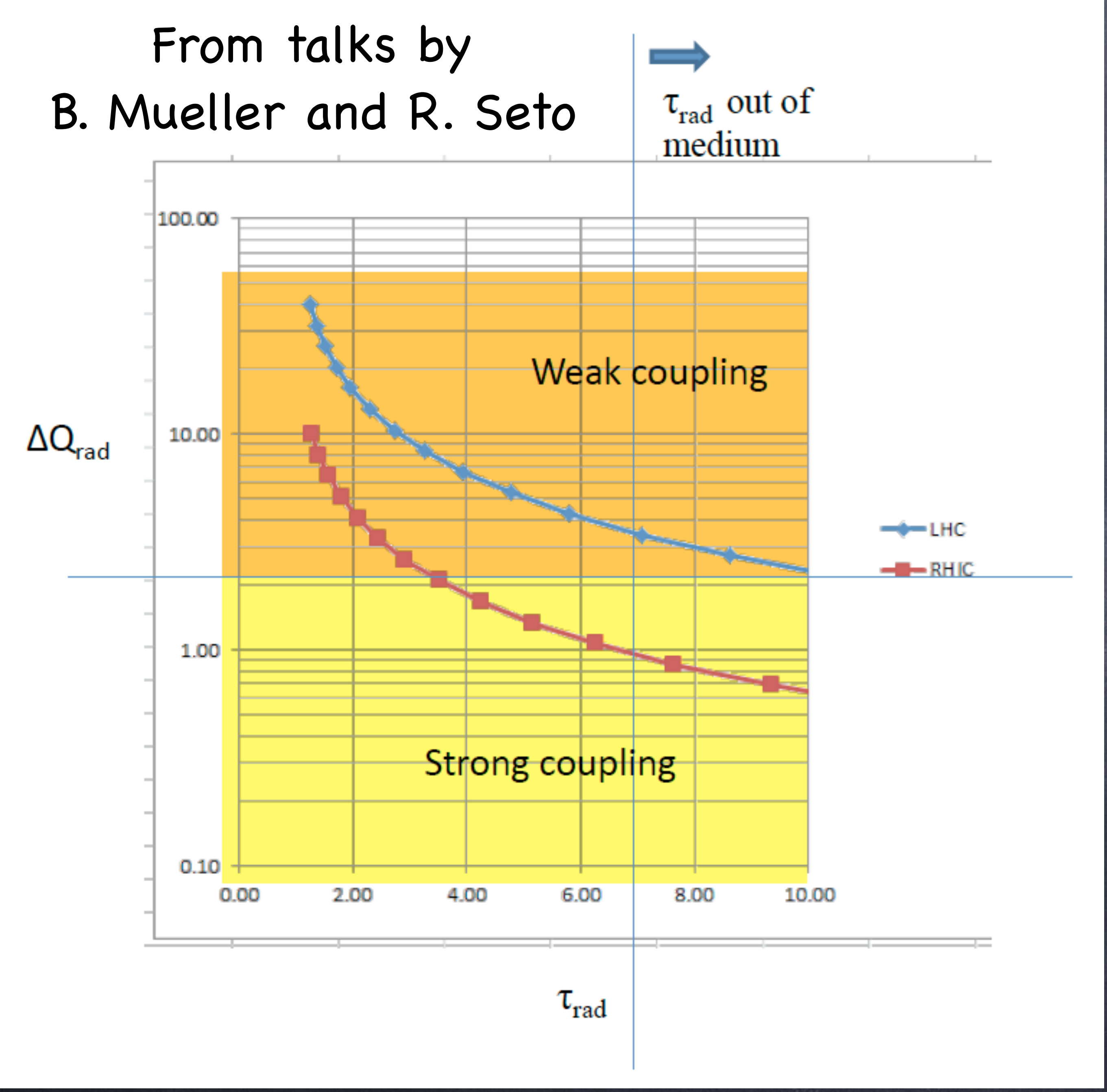
virtuality drops as more shower partons produced

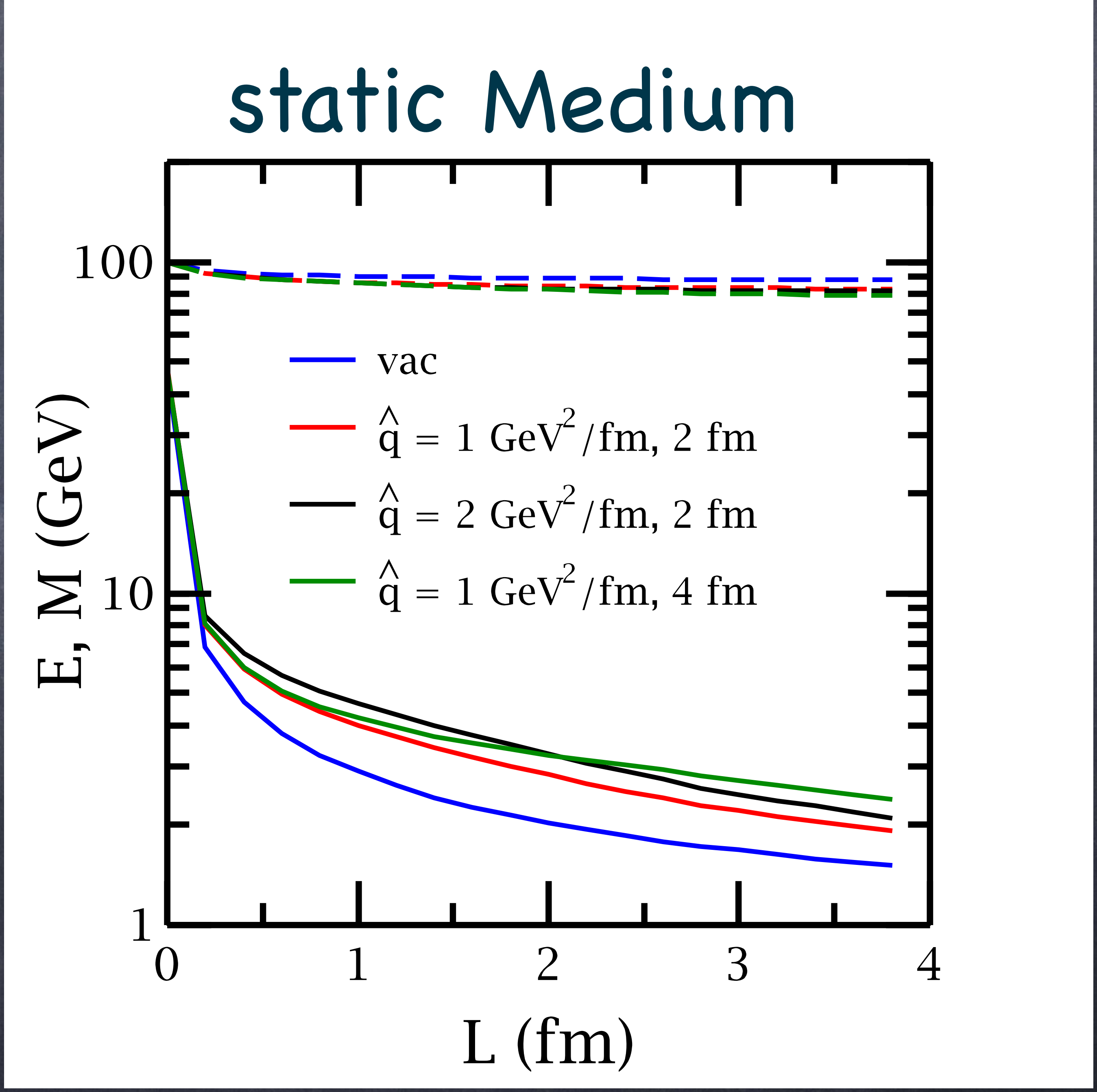
Reconstructed mass: $M \quad = \quad \sqrt{p^2 - p_T^2 - p_z^2}$

$$\vec{p}_T \quad = \quad \sum_{i=1}^{n} \vec{p}_{T_i}, \quad p_T = |\vec{p_T}|, \quad p_{T_i} = |\vec{p_{T_i}}| \qquad p_z \quad = \quad \sum_{i=1}^{n} p_{T_i} \sinh \eta_i, \quad p = \sum_{i=1}^{n} p_{T_i} \cosh \eta_i.$$

What happens to the leading parton in vacuum/medium?

Virtuality or mass drops much more quickly than Energy

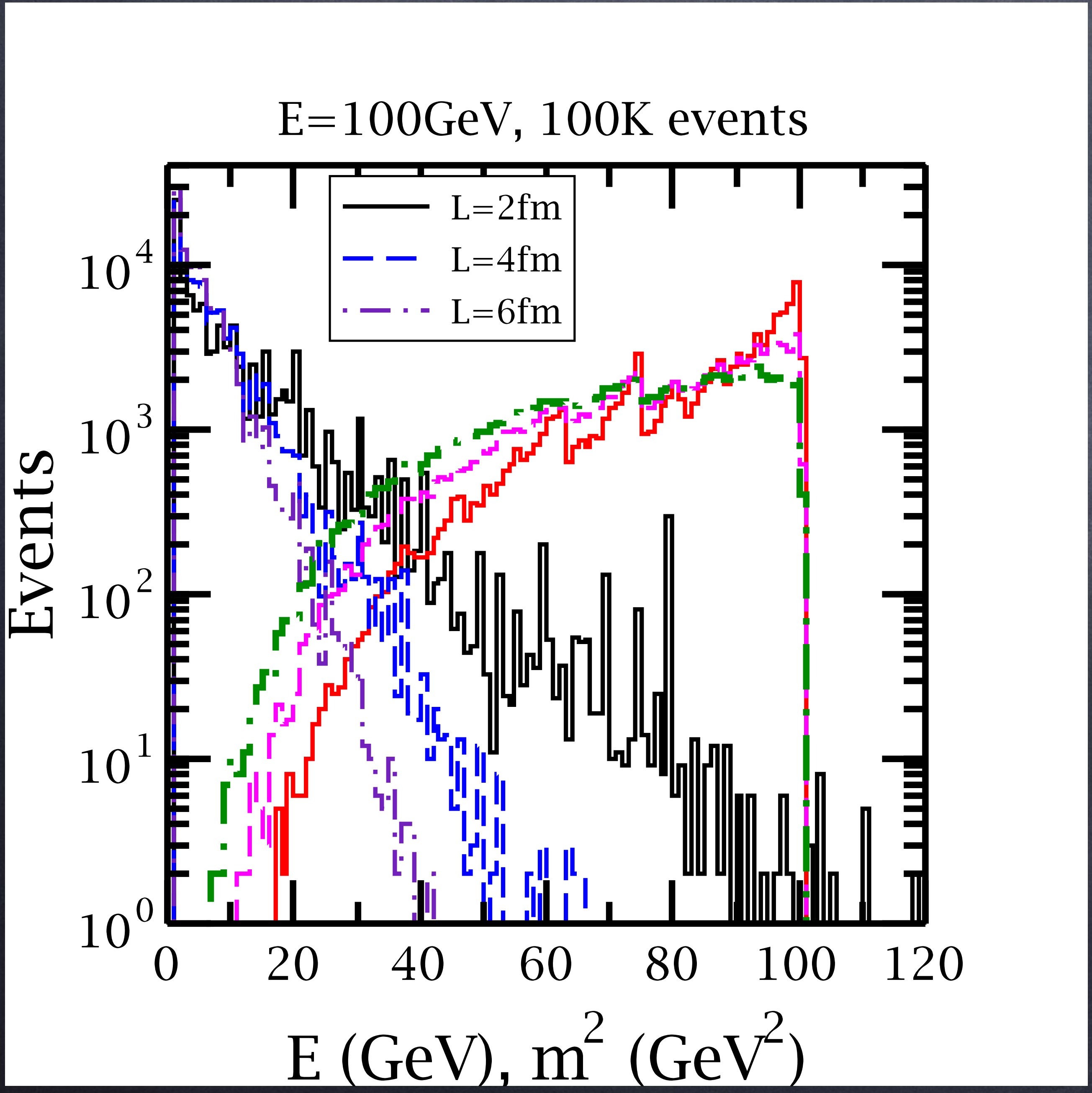


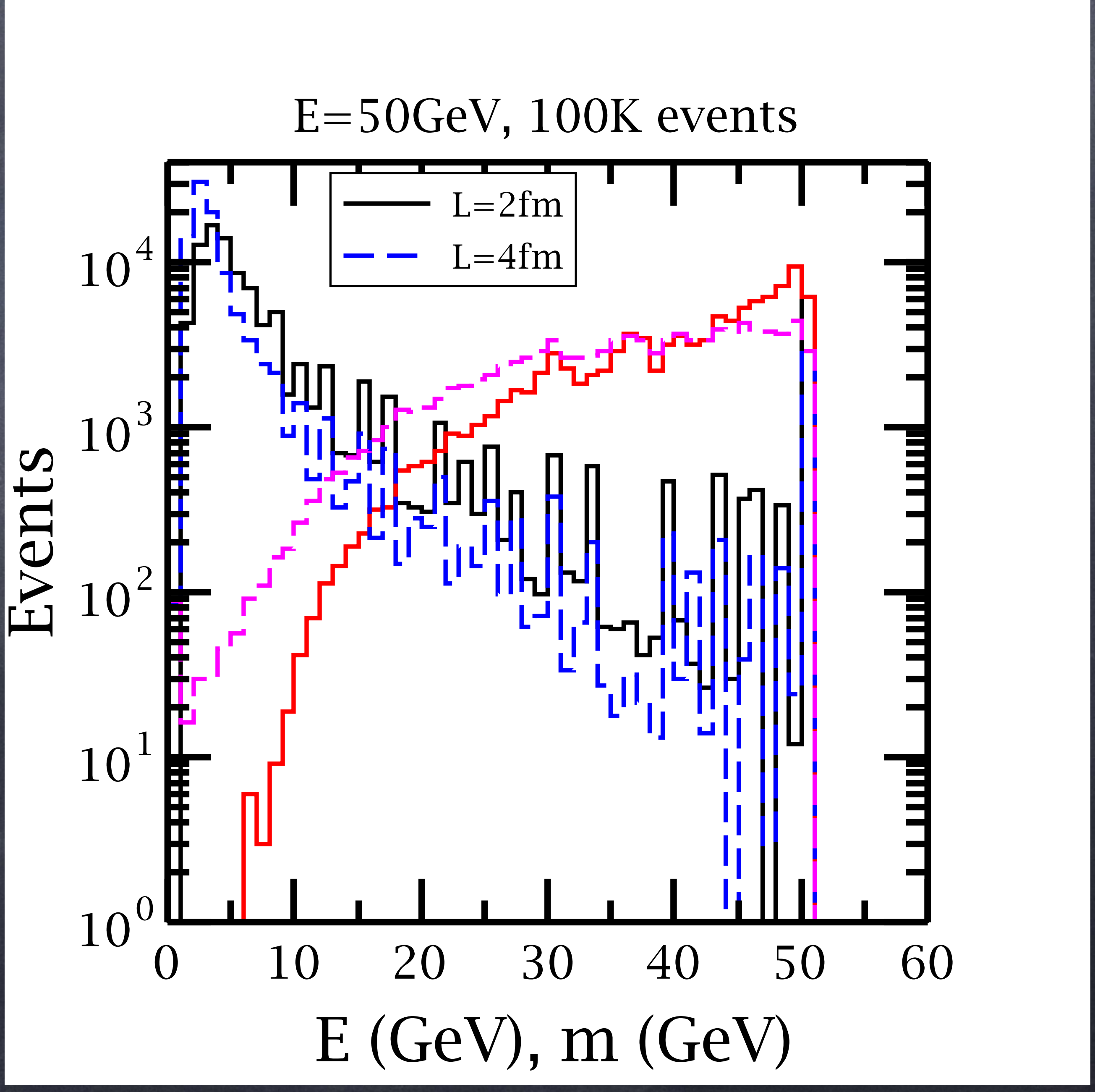


Note: once partons drop to 1GeV, no further splitting occurs

What happens to the leading parton in vacuum/medium?

How about the distributions?





Distribution of virtuality from initial hard scattering

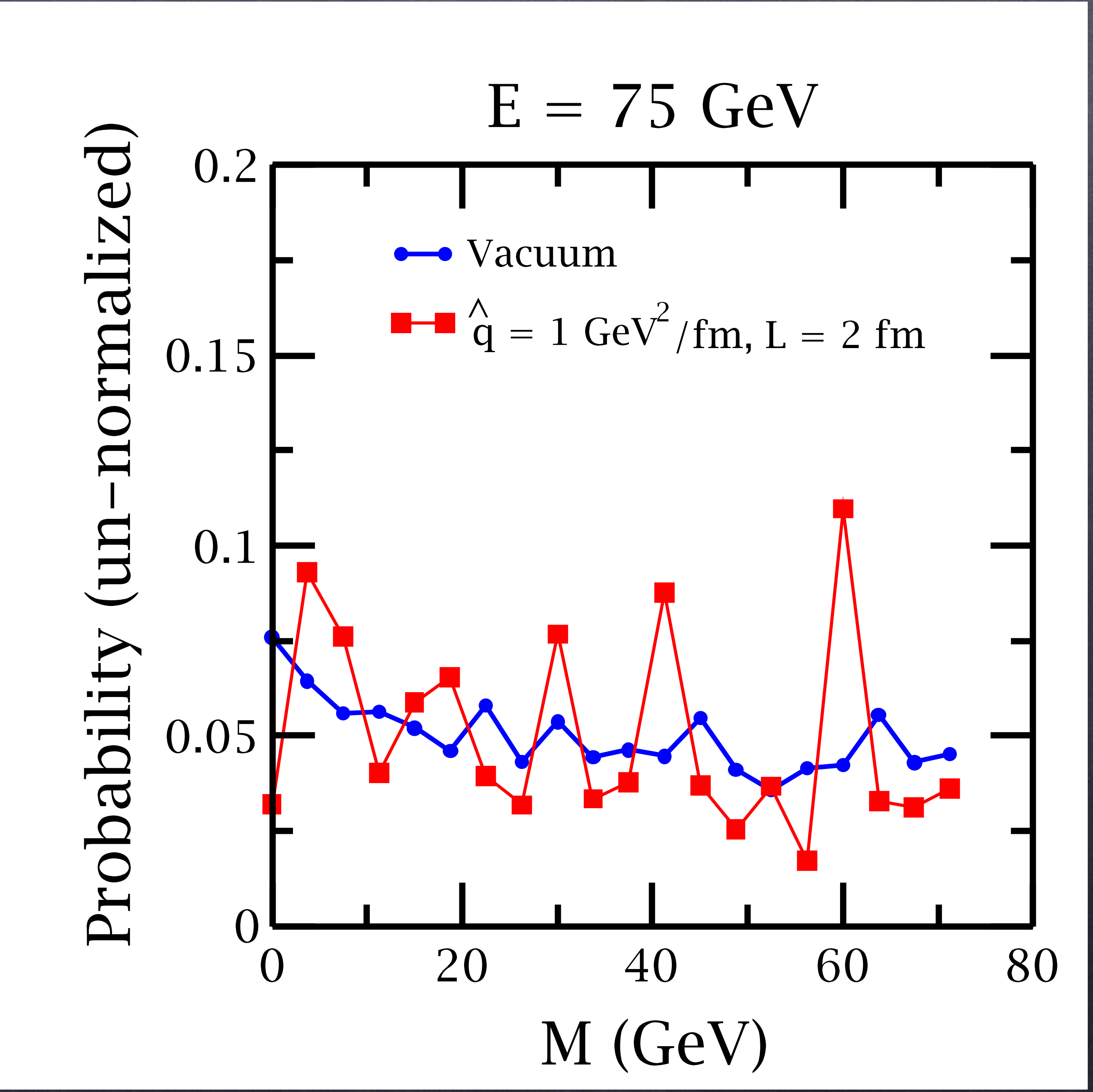
Jagged distribution due to fewer events

M<1GeV clubbed with 0 GeV point

For E = 75 GeV

scale = max. virtuality = 75 GeV

mass distribution of leading parton From MATTER with no initial state (100K events)



Distribution of virtuality from initial hard scattering

Jagged distribution due to fewer events

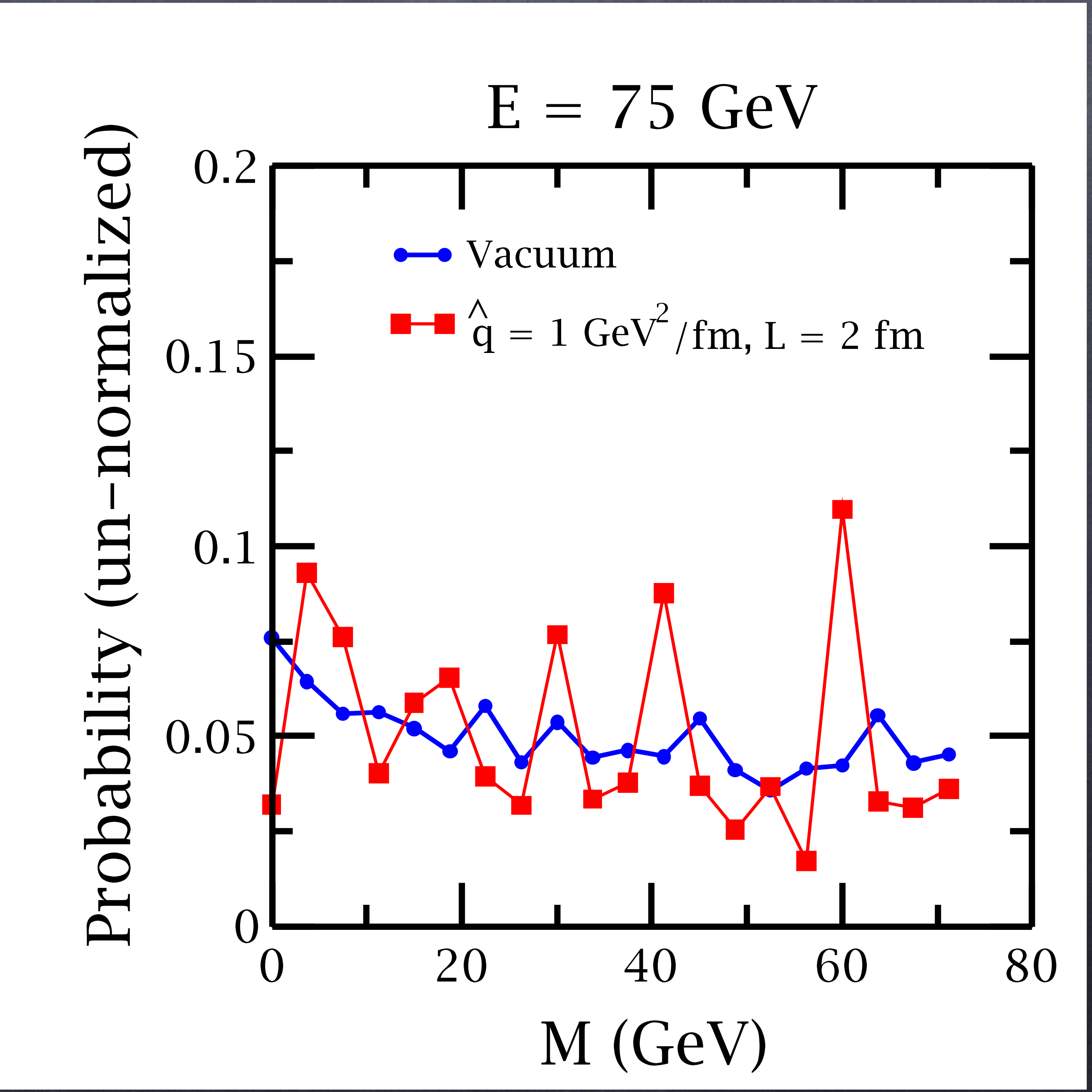
M<1GeV clubbed with 0 GeV point

For E = 75 GeV

scale = max. virtuality = 75 GeV

vs. Virt distribution of recon. Jet with q=1GeV^2/fm and L = 2fm

mass distribution of leading parton From MATTER with no initial state (100K events)



Distribution of virtuality from initial hard scattering

Jagged distribution due to fewer events

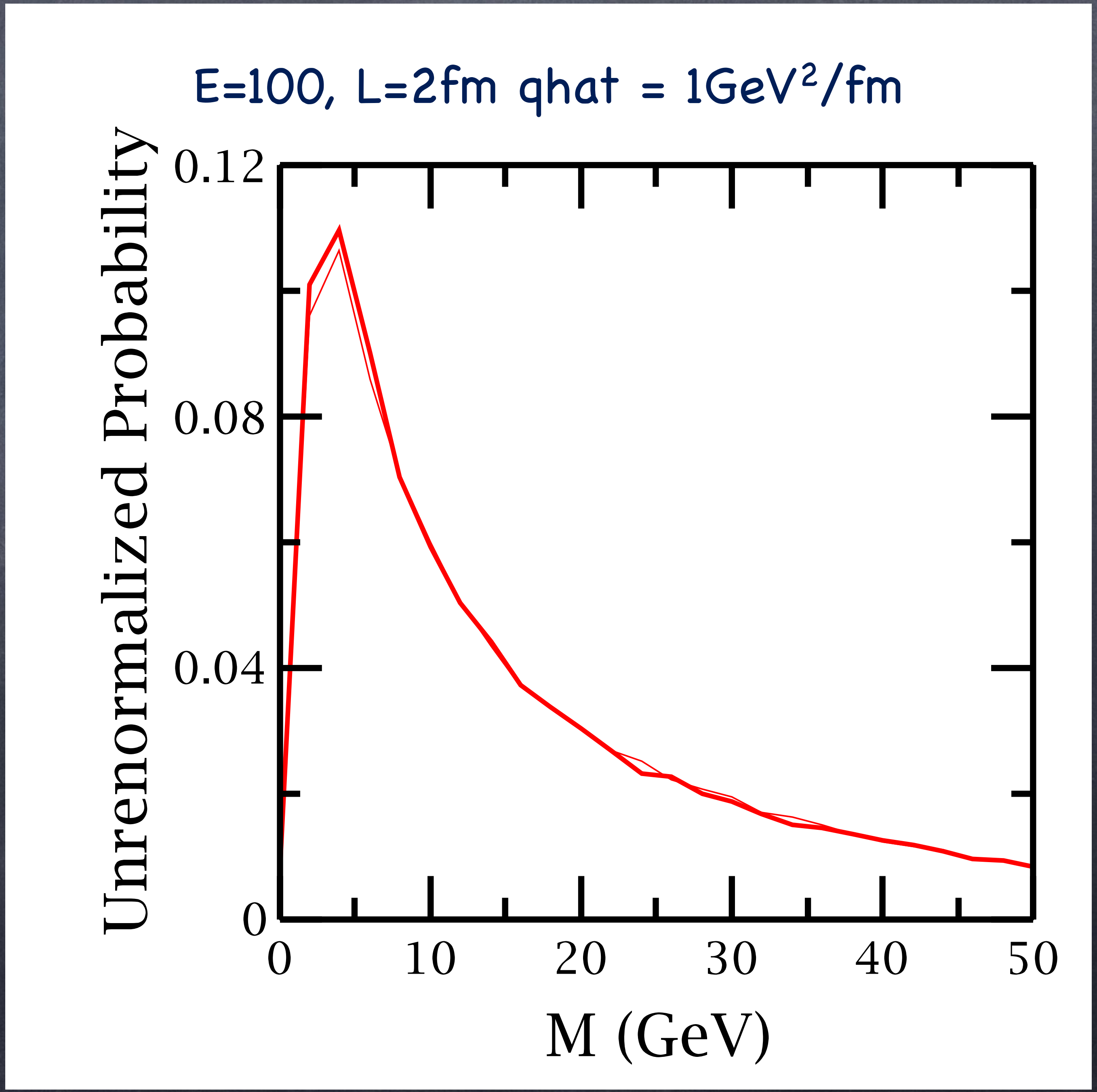
M<1GeV clubbed with 0 GeV point

For E = 75 GeV

scale = max. virtuality = 75 GeV

vs. Virt distribution of recon. Jet with q=1GeV^2/fm and L = 2fm

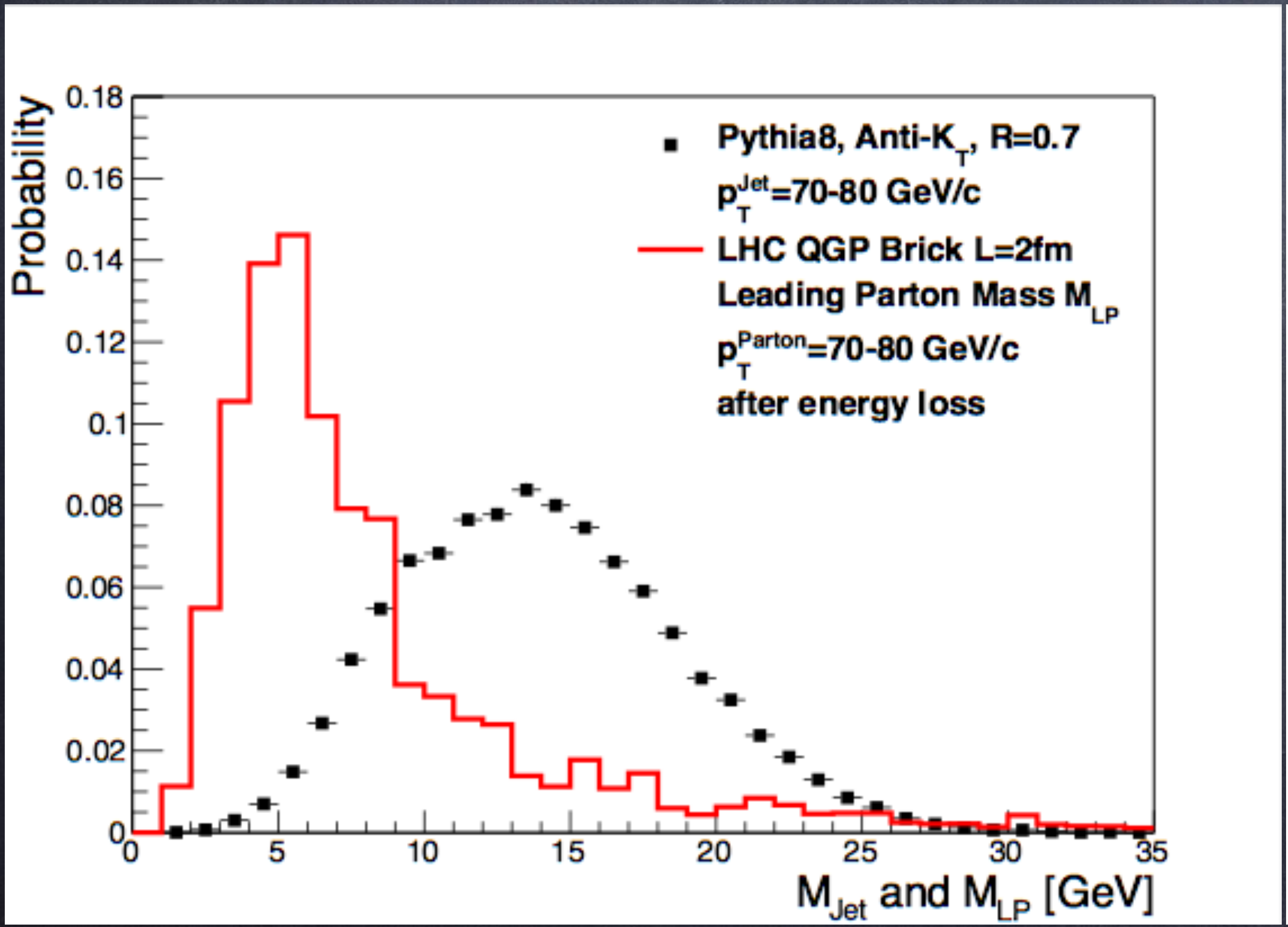
mass distribution of leading parton From MATTER with no initial state (100K events)



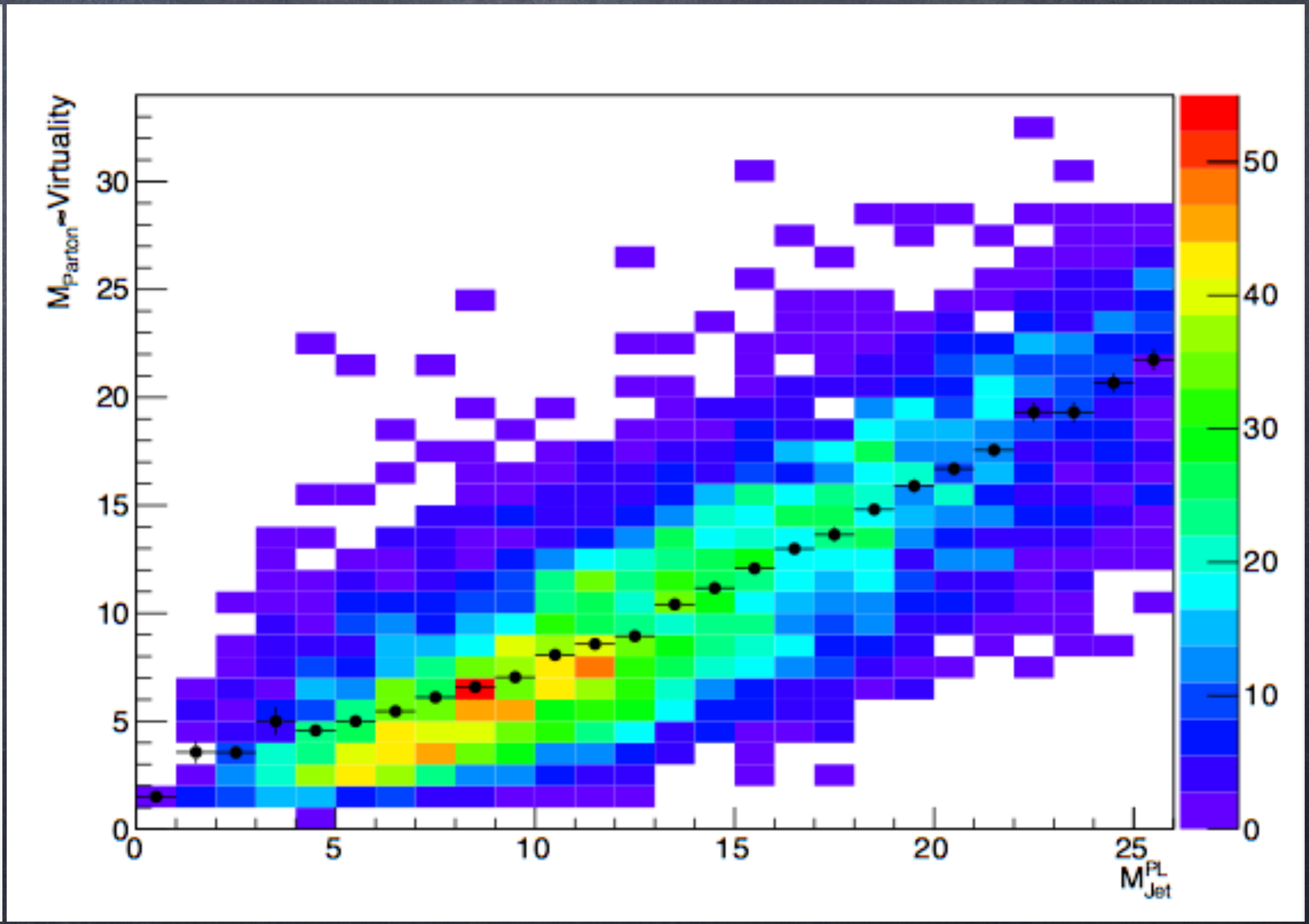
The large difference is also present for PYTHIA jets

Due to presence of hard scattering and initial state the mass distribution in PYTHIA has a peak
Here we use reconstructed mass,
which compares well with actual mass

Mass distribution of reconstructed jet in PYTHIA vs in-medium reconstructed jet



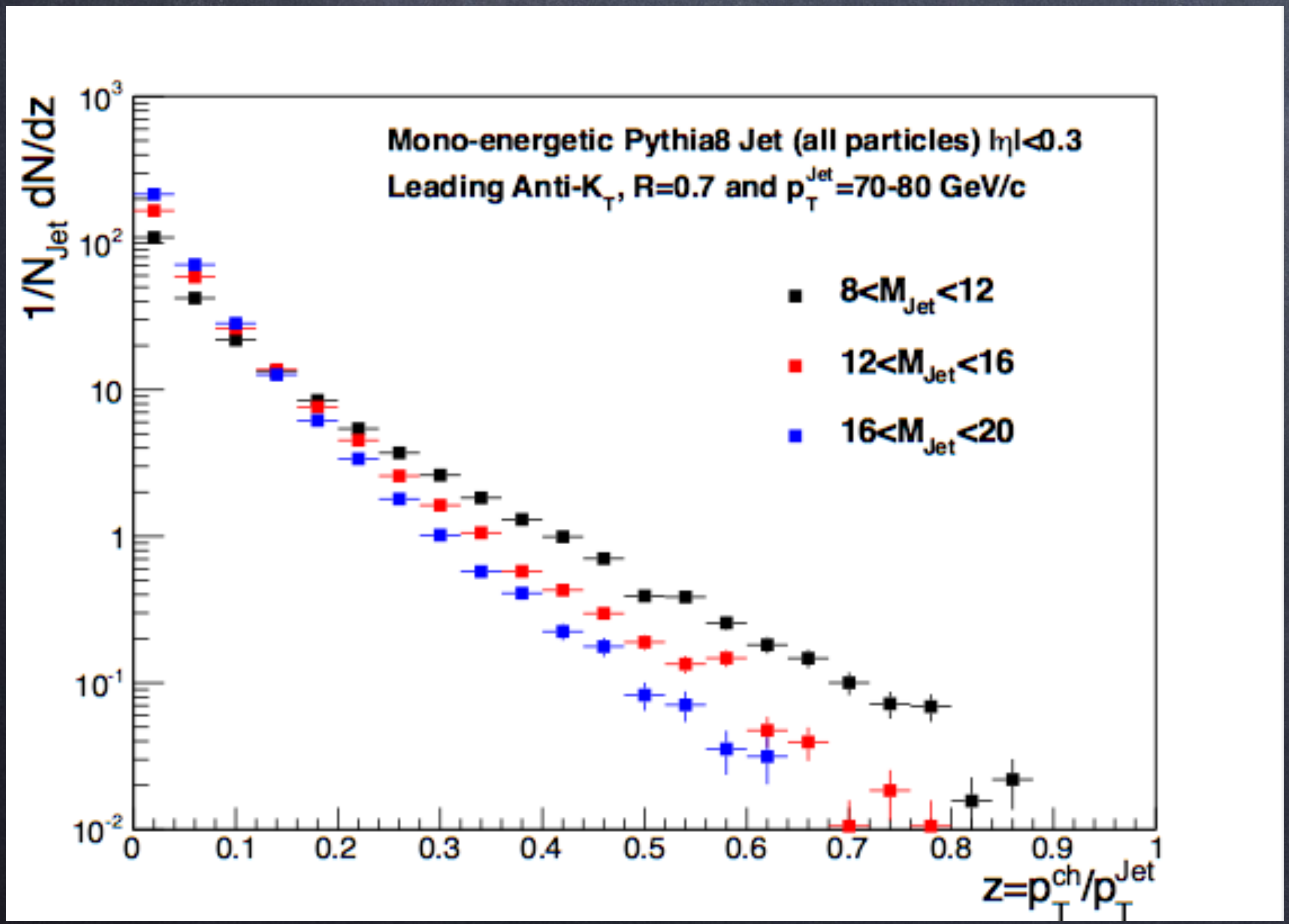
Reconstructed mass is very closely related to actual mass in PYTHIA

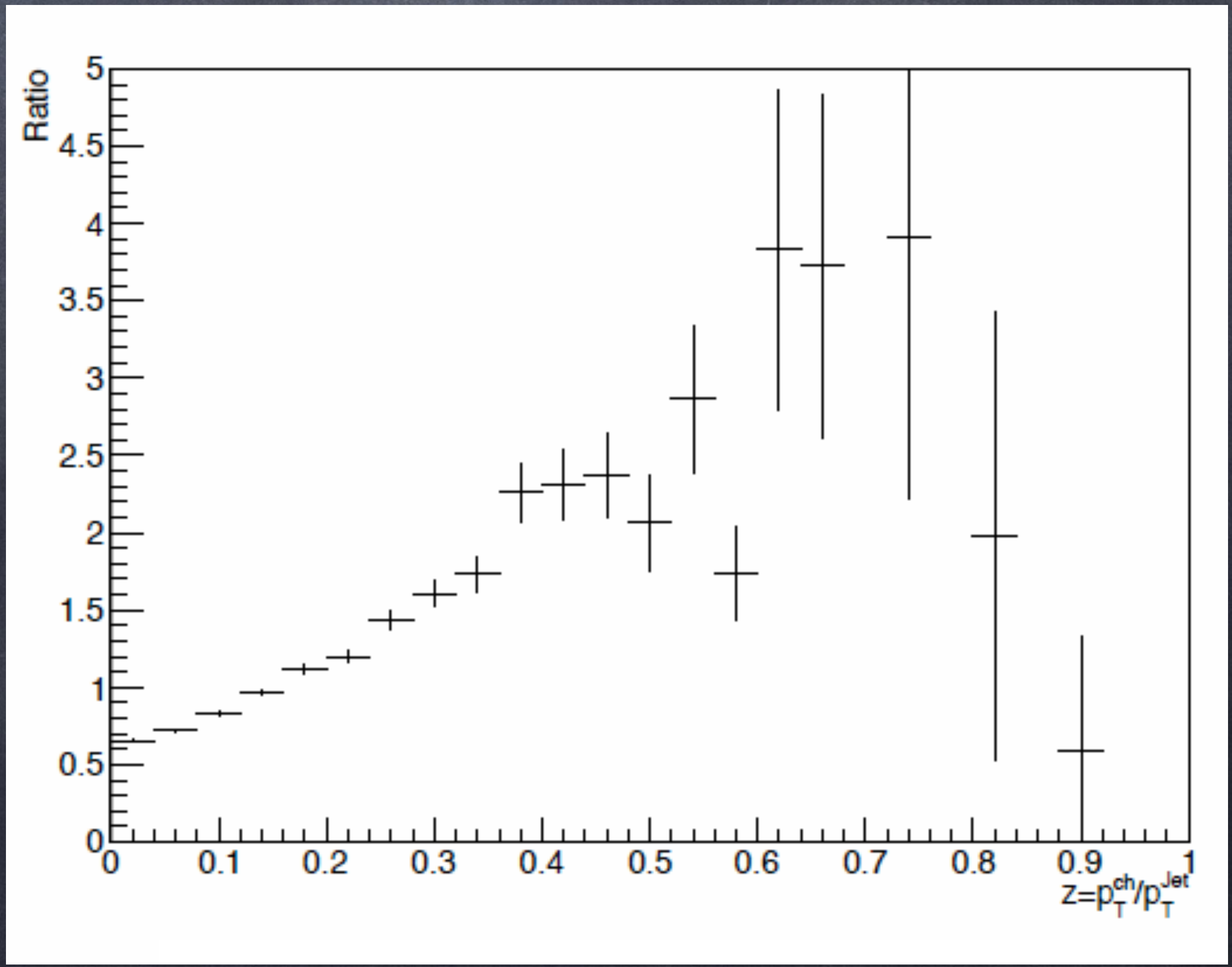


Reconstructed mass as a place holder for jet mass

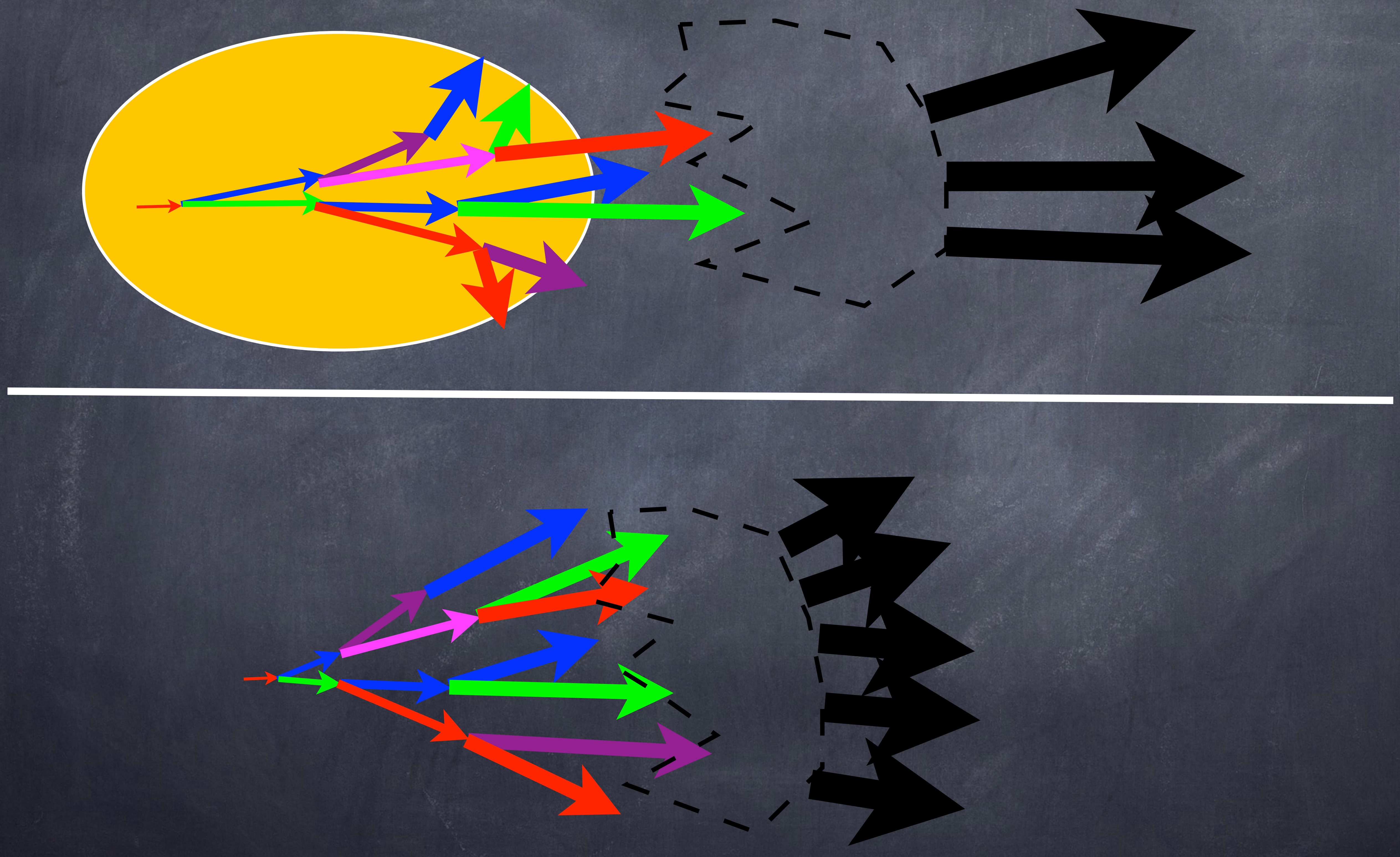
The jet fragmentation function for a given mass range is very sensitive to that mass range

sensitivity very similar to the scale dependence of fragmentation function





We are dividing two very different objects



Semi conclusions

While leading partons lose some energy in heavy-ion collisions

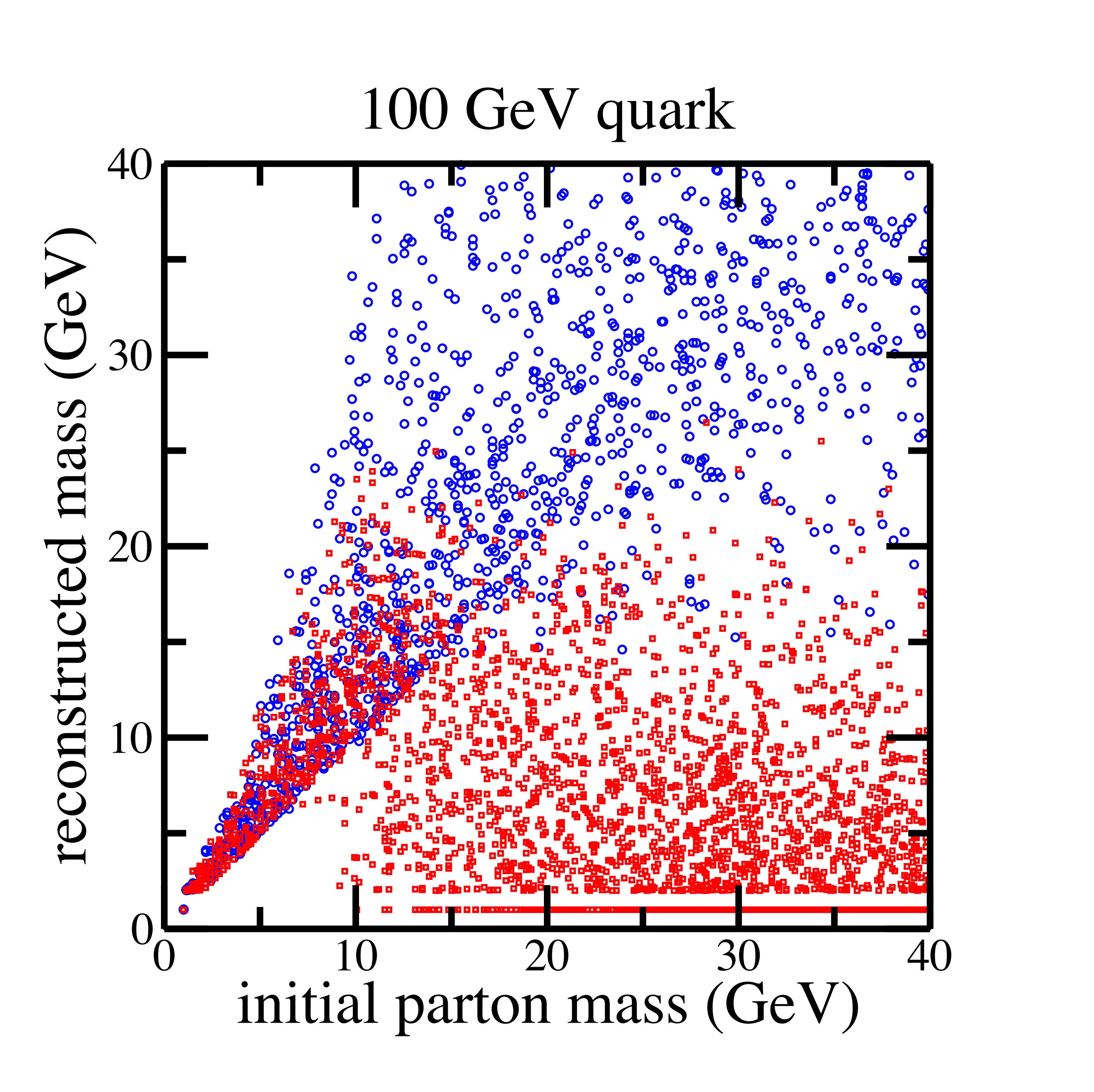
They lose a lot of mass in the course of radiation

If many of the soft partons are deflected in the medium, we are left with a mass-depleted jet

The mass of the depleted jet has a narrow distribution

This should be a noticeable effect if mass or some approximation to mass could be measured.

Reconstruction does have an effect on extracted mass of jet.



In general, 2 kinds of transport coefficients

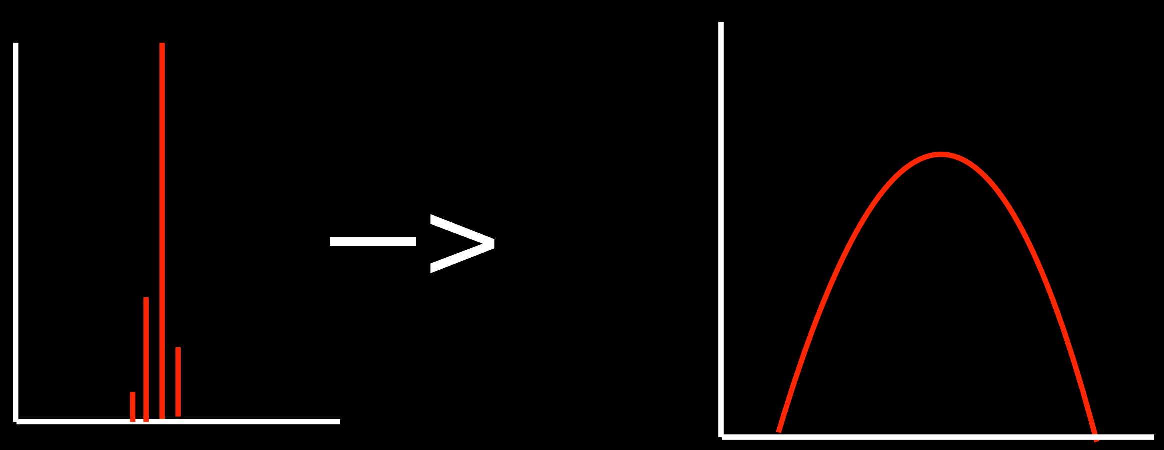
Type 1: which quantify how the medium changes the jet

$$\hat{q}(E,Q^2) \qquad \hat{q}_4(E,Q^2) = \frac{\langle p_T^4\rangle - \langle p_T^2\rangle^2}{L} \ldots$$

$$\hat{e}(E,Q^2) \qquad \hat{e}_2(E,Q^2) = \frac{\langle \delta E^2\rangle}{L} \qquad \hat{e}_4(E,Q^2) = \frac{\langle \delta E^4\rangle - \langle \delta E^2\rangle^2}{L} \ldots$$

Type 2: which quantify the space-time structure of the deposited energy momentum at the hydro scale

$$\delta T^{\mu\nu}$$



In general, 2 kinds of transport coefficients

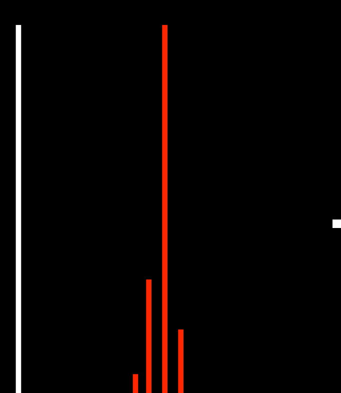
Type 1: which quantify how the medium changes the jet

$$\hat{q}(E, Q^2) \qquad \hat{q}_4(E, Q^2) = \frac{\langle p_T^4 \rangle - \langle p_T^2 \rangle^2}{L} \ldots$$

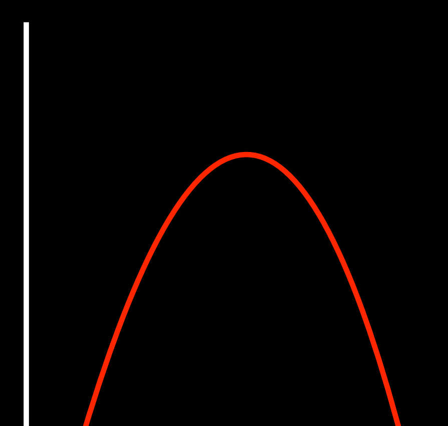
$$\hat{e}(E, Q^2) \qquad \hat{e}_2(E, Q^2) = \frac{\langle \delta E^2 \rangle}{L} \qquad \hat{e}_4(E, Q^2) = \frac{\langle \delta E^4 \rangle - \langle \delta E^2 \rangle^2}{L} \ldots$$

Type 2: which quantify the space-time structure of the deposited energy momentum at the hydro scale

$$\delta T^{\mu\nu}$$



–>



In general, 2 kinds of transport coefficients

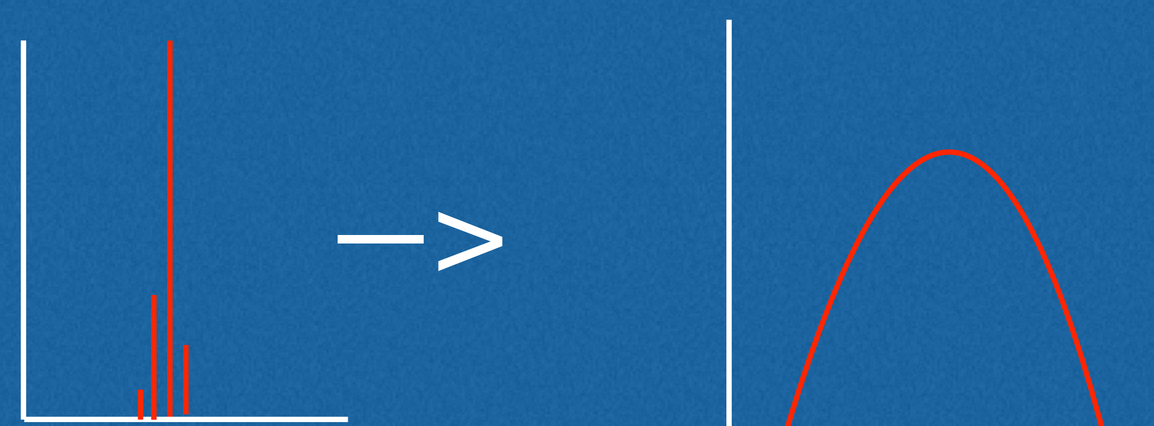
Type 1: which quantify how the medium changes the jet

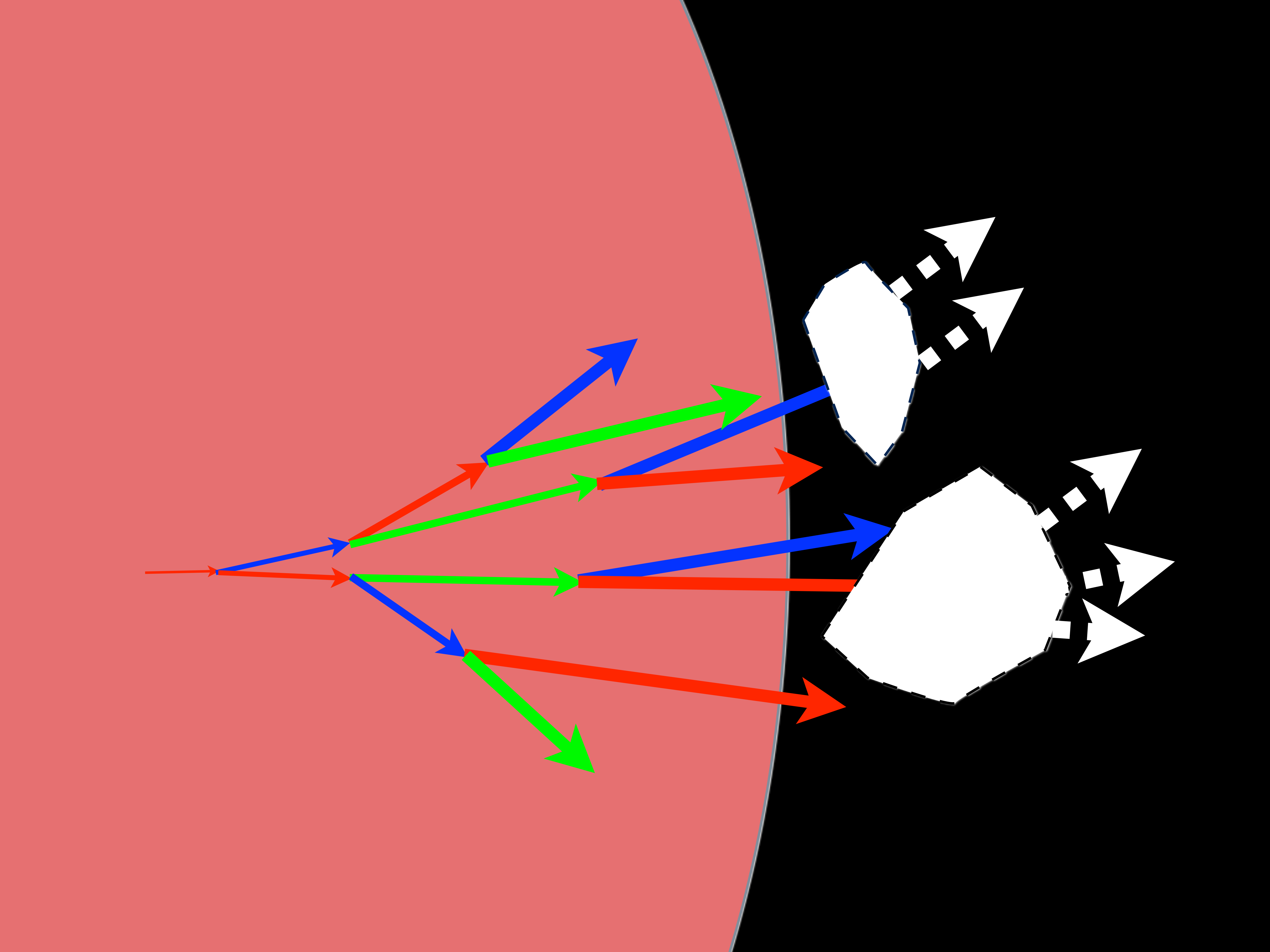
$$\hat{q}(E,Q^2) \qquad \hat{q}_4(E,Q^2) = \frac{\langle p_T^4\rangle - \langle p_T^2\rangle^2}{L} \ldots$$

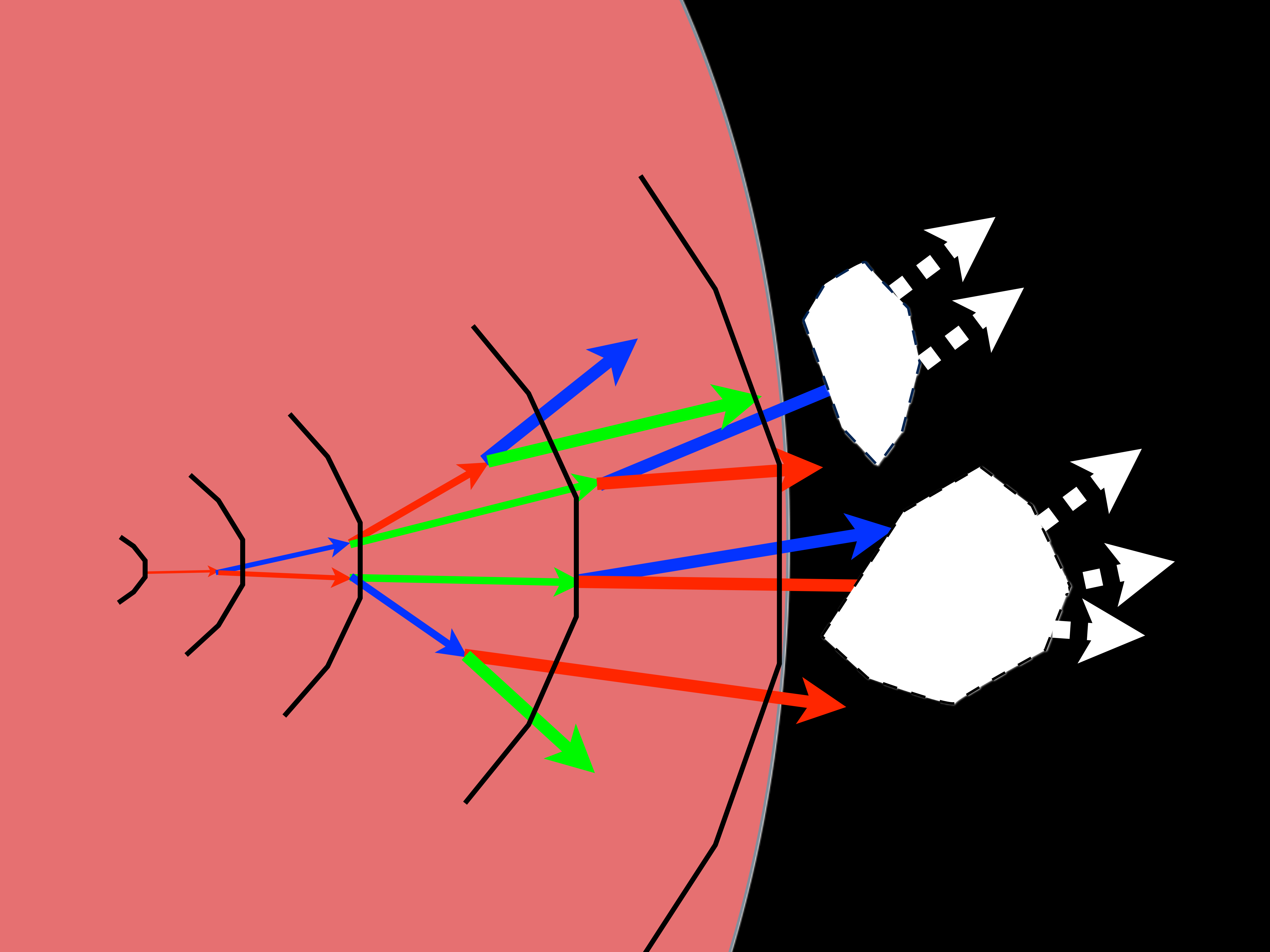
$$\hat{e}(E,Q^2) \qquad \hat{e}_2(E,Q^2) = \frac{\langle \delta E^2\rangle}{L} \qquad \hat{e}_4(E,Q^2) = \frac{\langle \delta E^4\rangle - \langle \delta E^2\rangle^2}{L} \ldots$$

Type 2: which quantify the space-time structure of the deposited energy momentum at the hydro scale

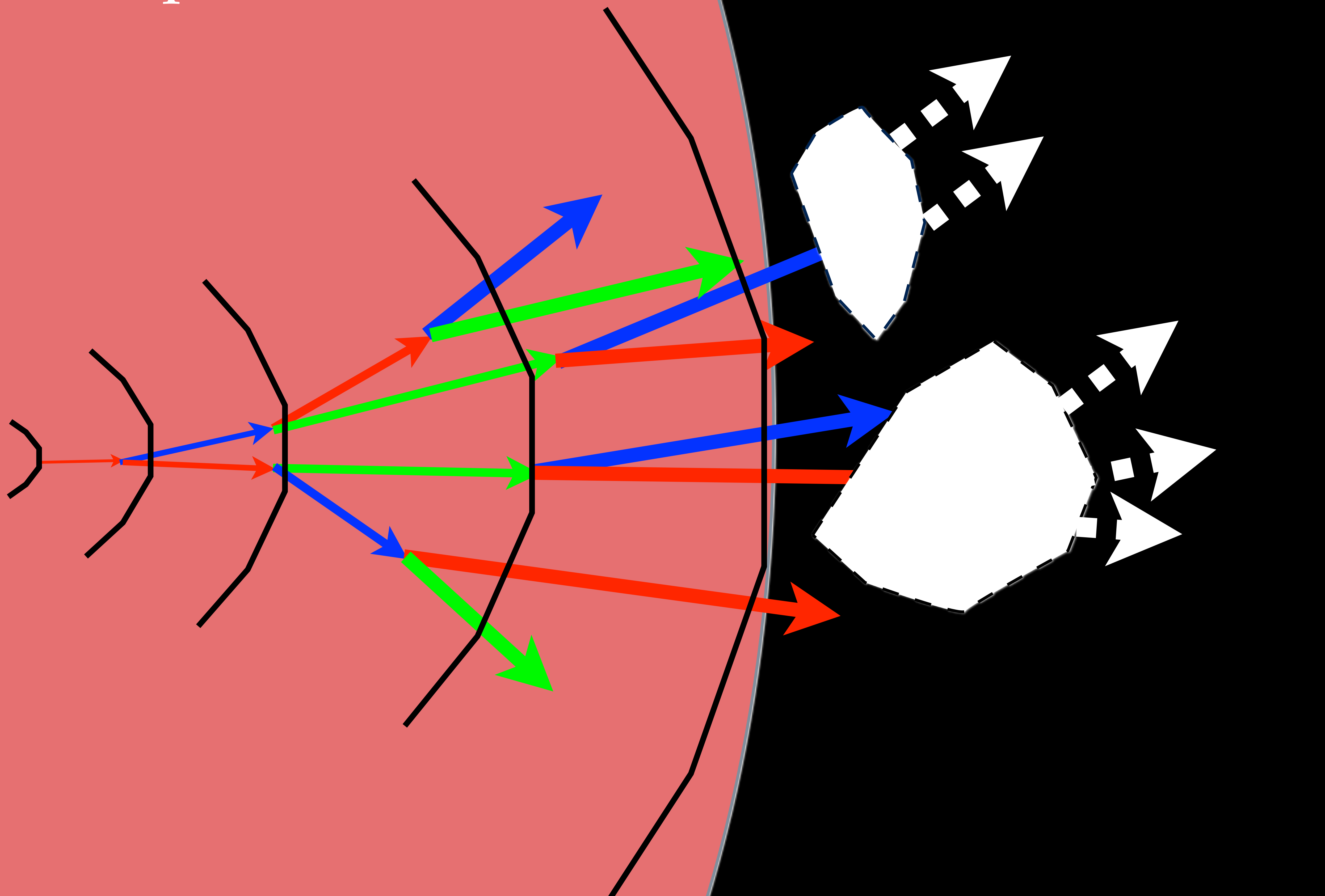
$$\delta T^{\mu\nu}$$



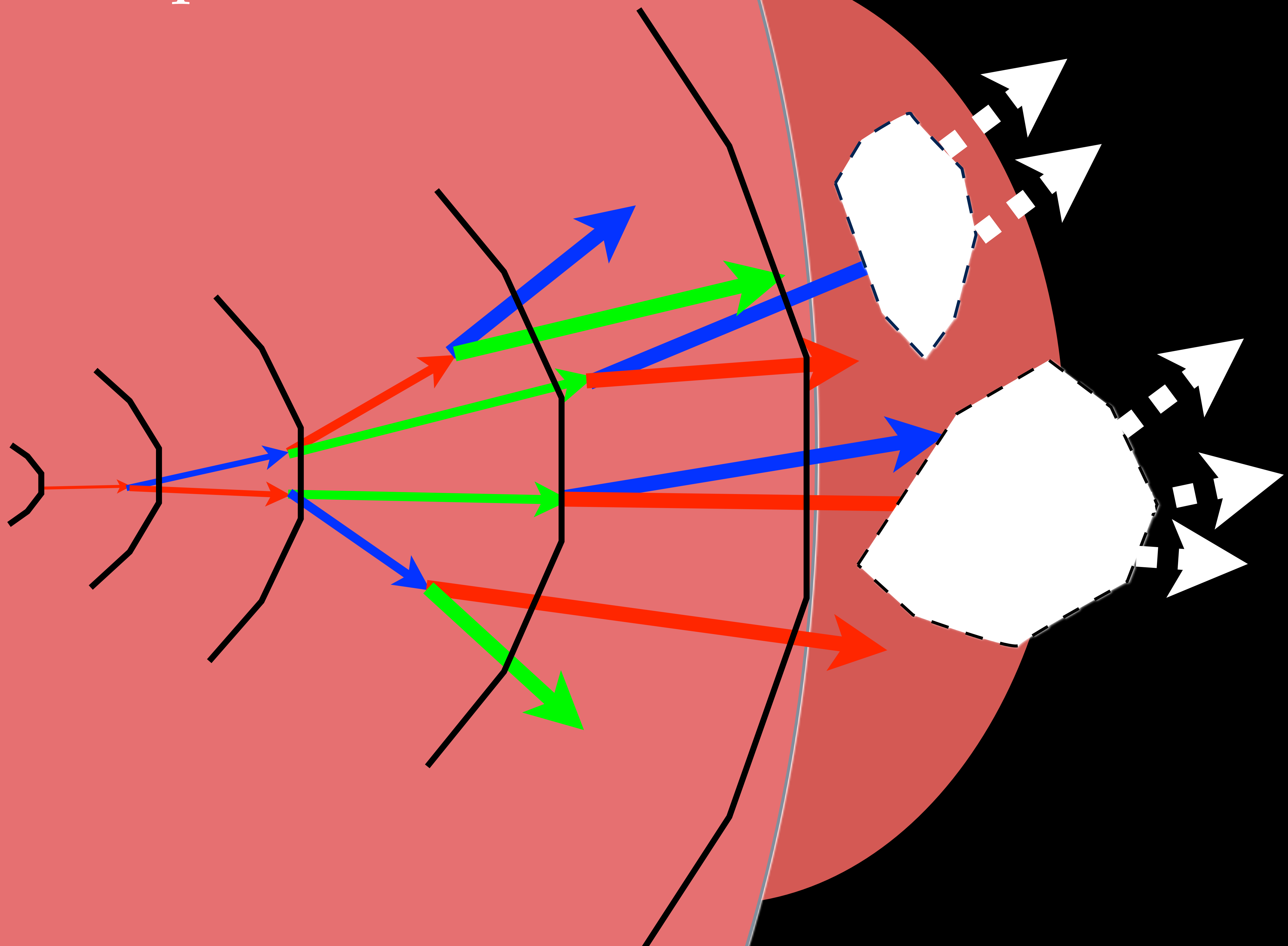




The modification of the underlying medium depends on these new coefficients



The modification of the underlying medium depends on these new coefficients



Conclusions II

Strong coupling input needed in event generators

Not just to complete the shower process

But to describe the redistribution of energy in jet cone that will effect the mass.